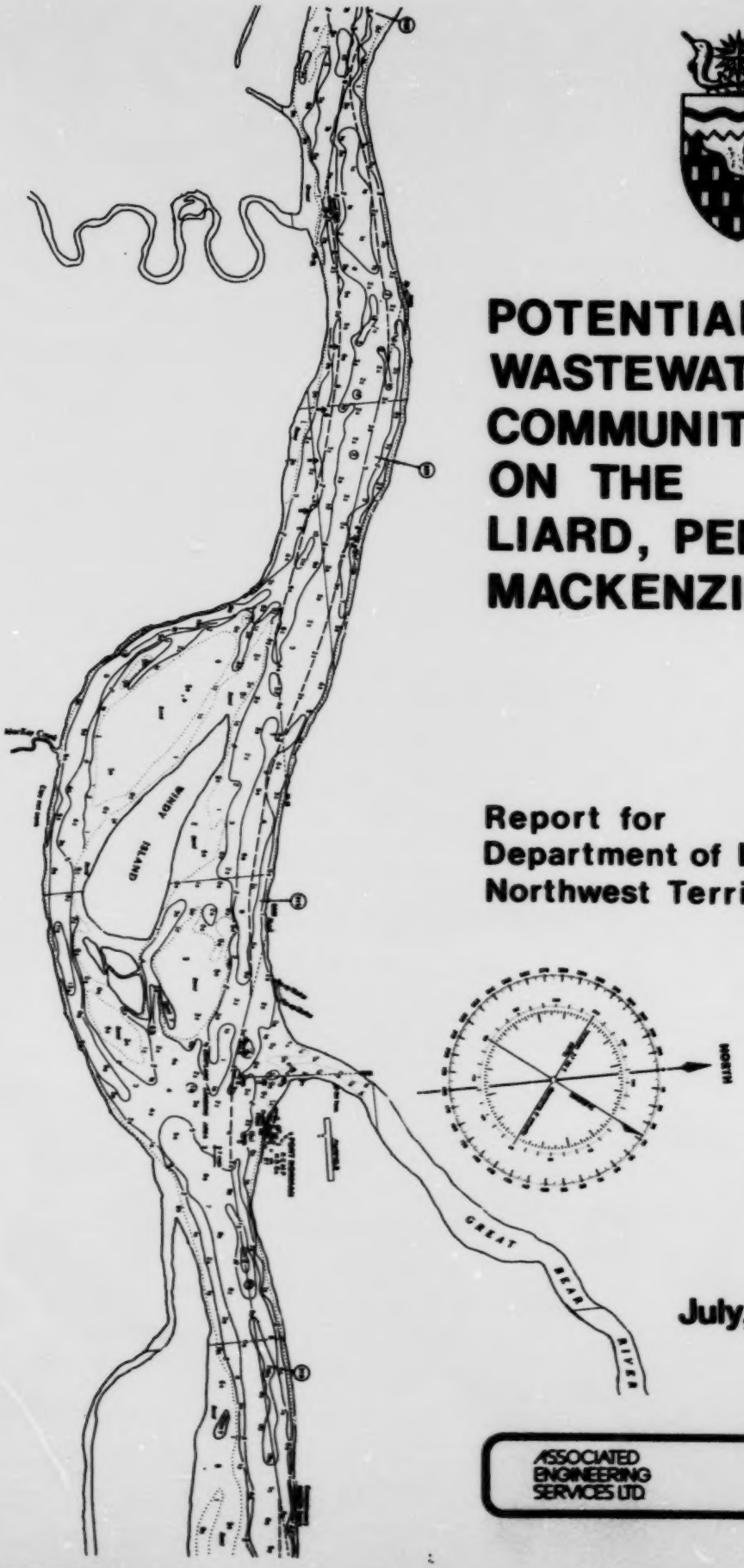

POTENTIAL IMPACT OF WASTEWATER FROM COMMUNITIES ON THE LIARD, PEEL AND MACKENZIE RIVERS

Report for
Department of Local Government,
Northwest Territories

July, 1978

ASSOCIATED ENGINEERING SERVICES LTD
AESL

CIATED ENGINEERING SERVICES LTD 13140 - ST. ALBERT TRAIL, EDMONTON, ALBERTA, T5L 4R8. TEL. (403) 453-8111. TELEX: 037-2333

August 26, 1982
File: E067

Municipal Affairs Division
Department of Local Government
Government of the Northwest Territories
Yellowknife, N.W.T.
X0E 1H0

Attention: Mr. Bob Milburn, P.Eng.

Dear Sir:

In response to your recent request, we are please to provide you with 100 additional copies of our report entitled "Potential Impact of Wastewater from Communities on the Liard, Peel and Mackenzie Rivers."

As you know, the report describes the effects that discharge of sewage from NWT communities would be expected to have on the NWT portions of the rivers mentioned, based on an extensive review of published information. Its main conclusion is that most effects would be immeasurably small, but possible persistence of microorganisms would demand particular consideration.

It is a pleasure to know that your interest in this report continues, and we hope that it will remain useful to you in the management of your Program.

Yours truly,

Richard E.K. Peilden, P.Eng.

REKP/sah

Encl.

ASSOCIATED ENGINEERING SERVICES LTD 13140 - ST. ALBERT TRAIL, EDMONTON, ALBERTA, T5L 4R8. TEL. (403) 453-8111. TELEX: 037-2333

July 24, 1978
File: EG67

Municipal Affairs Division
Department of Local Government
Government of the Northwest Territories
Yellowknife, N.W.T.
X0E 1H0

Attention: Mr. Vern Christensen, P. Eng.

Dear Sir:

We are pleased to submit 35 copies of our report entitled "Potential Impact of Wastewater from Communities on the Liard, Peel and Mackenzie Rivers." The report describes the effects that discharge of sewage from NWT communities would be expected to have on the NWT portions of the rivers mentioned, based on an examination of existing literature, as requested by yourself about December 21, 1977. Its main conclusion is that most effects would be immeasurably small, but possible persistence of microorganisms would demand particular consideration.

In the course of the study, we have received assistance from a number of sources. Specific contributions are acknowledged in the List of References. We also wish to thank you for the help you have given on a number of occasions, in searching out useful material and in providing advice and guidance.

.../2

ASSOCIATED ENGINEERING SERVICES LTD

July 24, 1978
File: BG67

Municipal Affairs Division

- 2 -

It has been a pleasure to work with you on this study. We hope that our findings will be useful to you in the planning and management of your Water and Sanitation Program.

Yours truly,

M.J. Stewart, Ph.D., P. Eng.

T.R. Lidkea, M.A.Sc.,

H.D. Hext, M.A.Sc., P. Eng.

R.E.K. Feilden, P. Eng.

EXECUTIVE SUMMARY

Potential Impact of Wastewater from Communities on the Liard, Peel and Mackenzie Rivers

Report for Municipal Affairs Division
Department of Local Government
Government of the Northwest Territories

Thirteen Northwest Territories communities are located on the banks of the Liard, Peel, and Mackenzie Rivers. They range in size from Jean Marie River (1978 population 60) to Inuvik (1978 population 3100). The question of what degree of sewage treatment will be necessary in these small, generally non-industrialized communities has yet to be resolved. For most, the obvious (or only) choice of ultimate disposal point for sewage is the adjacent river. Several already do discharge sewage into the rivers, some with and others without prior treatment. Recognizing a need to develop rational guide-lines for the design of improvements to community water supply and sewage treatment facilities, Department of Local Government commissioned the study of sewage effects described in this report. The purpose of the study was to determine, in terms of order-of-magnitude, how great an impact municipal wastewater from existing NWT communities could have on the Liard, Peel and Mackenzie Rivers, and thereby to identify locations and effects which would warrant further consideration.

The regimes of the three rivers under consideration vary greatly over their annual cycles. During the summer months, flows are high. Waters are very turbid over all reaches except for the Mackenzie upstream of its confluence with the Liard, but water quality in other respects satisfies the standards and objectives for drinking water published by Department of National Health and Welfare, Canada. In winter, the rivers are ice-covered and flows decline to a small fraction of summertime peaks. Turbidity also falls to low levels. The waters tend to be slightly hard, and quite low in dissolved oxygen (declining to around 5.0 mg/l).

The Liard, Peel and Mackenzie Rivers provide habitat for fish, water fowl, and aquatic mammals. Man uses them for domestic water supplies, as sources of fur bearing animals and of edible fish and water fowl, and as transportation routes. Potential uses include recreation, industrial water supply, generation of hydroelectric power, stock watering and crop irrigation. Of these uses, domestic water supply and fishing would be most affected by sewage. Effects which would not jeopardize these uses would not be detrimental to others. Therefore, only the effects on fish and domestic water supplies have been considered in the assessment.

Because capacities for dilution and dissolved oxygen concentrations reach their natural minimum values towards the end of winter, it seems clear that the magnitudes of sewage effects on the river environment and on the quality of river water would be greatest towards the end of winter. It also follows that sewage effects which would not exceed acceptable levels under winter regime, would remain well within acceptable ranges during other times of the year. Therefore, in the Study, sewage impacts have been assessed only for the most critical conditions, such as lowest flow, lowest river velocity, lowest dissolved oxygen level, recorded to date at the river locations under consideration. Further, forecast year-2000 populations, rather than 1978 populations, were used in estimating potential sewage discharges from the thirteen study communities. While this approach may appear overly conservative, it has the advantage of establishing an upper limit on the magnitude of wastewater effects through relatively simple procedures. Any attempt to model the interaction of wastewater with elements of the aquatic environment throughout an annual regime cycle would be a vastly more complex undertaking.

The constituents of domestic sewage which have the most critical environmental and public health effects on receiving waters are pathogenic (disease-causing) micro-organisms, constituents which demand oxygen for decomposition processes and therefore compete with aquatic life which also needs oxygen, solids which remain suspended and therefore make the water turbid, nutrients (phosphate and nitrogen) which stimulate growth of aquatic plants, and dissolved solids which change the chemical quality of the water.

The quantities of each of these constituents that forecast year 2000 populations at each of the study communities would produce were estimated, using generally accepted values for per-capita production rates. The effects that the predicted quantities of each constituent would have on each study river, under the least favourable seasonal conditions recorded to date, were then calculated. It is considered that these calculated effects represent the estimated worst case condition in the foreseeable future if all the study communities were to discharge their sewage directly to the Liard, Peel and Mackenzie Rivers.

1. Micro-organisms

Even in remote wilderness areas, lake and river waters may carry varieties of micro-organisms harmful to man which are also hosted by wild animals. Drinking surface water from any source before it is disinfected by boiling, chlorination or some other effective means, always entails a risk to health. Consequently, Canadian standards for drinking water require disinfection of water from all surface sources before distribution to the public. This requirement applies to water from the study rivers.

Because they are present in large numbers in domestic sewage, and because they are relatively easy to detect and measure, coliform bacteria have long been used as the standard indicator of the presence of sewage, and the potential presence of sewage-borne pathogenic micro-organisms. Through six or seven decades of experience, public health authorities have established correlations between concentrations of coliforms, and the water treatment processes necessary to maintain the threat to public health from water borne bacteria and viruses at acceptably low levels. Canadian drinking water standards require disinfection (only) for raw waters containing generally less than 10 fecal coliforms per 100 ml, filtration and disinfection if the count is between 10 and 100 per 100 ml, and additional processes if it tends to be above 100.

The concentrations of fecal coliforms that would be expected to be found in river water at each study community, as a result of continuous discharge of raw sewage from all study communities upstream, were calculated for minimum recorded river flows. At ten of the thirteen study communities, the concent-

rations would be below 10 per 100 ml, that is, water treatment requirements would be unaffected. At the other three, Norman Wells, Fort Good Hope and Aklavik, concentrations were predicted to be in the range 10 to 32 organisms per 100 ml, therefore, public health standards might require the installation of filters in water supply systems drawing river water at these locations. However, it is noted that Norman Wells' water is drawn from a reservoir on Bosworth Creek, and not from the Mackenzie River. Therefore Norman Wells would not be affected by upstream sewage discharges, unless its water supply were changed over to the Mackenzie, either temporarily or permanently. It is also noted that of the fecal coliform concentration of 10 per 100 ml predicted to arrive at Fort Good Hope, 7 would come from Norman Wells, and of the 13 per 100 ml predicted to be found at Aklavik, all would be from Fort McPherson. Therefore, if micro-organism concentrations in sewage effluent from Norman Wells and Fort McPherson were to be reduced sufficiently through sewage treatment processes, then discharge of sewage from all study communities would not be expected to create a need for filtration of river water to be used for public distribution, at any study community.

In making these estimates, it was assumed that waste discharges from each community were completely mixed across the river before the flow reached the next community downstream. In fact, mixing is a phenomenon which occurs gradually, over many hundreds of miles of travel, and therefore would not be complete. Actual coliform concentrations encountered at a downstream water intake would depend to a large extent on the locations of upstream outfalls, and the intake, in the river cross-section. Coliform counts could be more or less than estimated. A sampling programme would be needed to establish actual levels.

Edible fish are taken from the study rivers in large numbers, so consideration was given to the public health implications of discharging raw sewage into fishing areas. Published research indicates that risks would not be significant, and that they would be far outweighed by the ordinary risks of contamination of fish during cleaning and other handling, and of tapeworm and liver fluke infection (not related to sewage). Fisheries researchers also point out that all risks arising from sewage in the environment, contamination during cleaning, and fish parasites, can be eliminated by cooking the fish before eating.

2. Biochemical Oxygen Demand

Surface waters normally contain dissolved oxygen, most of which is obtained from the air above the water's surface. During daylight periods, some oxygen may also be produced by water plants and algae, by photosynthesis. In winter, ice cover cuts off much of the oxygen supply to the study rivers, and dissolved oxygen concentrations fall from summertime levels of 10 to 11 mg/l to around 5 to 7 mg/l. Fish and other aquatic animal forms require oxygen to live, and indications are that the minimum concentration which will support a healthy fish population in cold fresh water is in the range of 6 mg/l.

The bacteria and micro-organisms which decompose and stabilize the organic content of sewage also use oxygen, if it is available. When sewage is discharged into a water body, populations of these organisms increase, in proportion to the quantity of nutrient made available. This requirement is termed the "biochemical oxygen demand" (BOD) of the sewage. If sewage concentrations in a natural water body are high enough, the BOD of the sewage may reduce dissolved oxygen levels to the point where a healthy fish population cannot be sustained.

The BOD which sewage discharges from each of the study communities would exert in the rivers were calculated. It was found that sewage discharges from twelve of the study communities would have insignificant effects (reduction less than 2% of minimum background levels) on the average level of dissolved oxygen over the full width of the stream. At the remaining location, Inuvik, a relatively large community faces a stream (East Channel of the Mackenzie River) having relatively little flow in wintertime. The combination is such that discharge of sewage from Inuvik in wintertime could cause significant oxygen depletion.

A further check was made, in which it was assumed that all of the BOD was exerted across only one percent of the width of the stream. This check indicated that sewage discharges from Aklavik and Fort McPherson might also result in remotely significant effects over limited areas.

3. Suspended Solids

Rivers carry in suspension greater or lesser amounts of fine solid particles, the concentration of which depends on such factors as the velocity and turbulence of flow, and characteristics of the land surface in the upstream region of the drainage basin. The amount and concentration of suspended materials carried by the study rivers varies enormously during the seasonal regime cycle, from as low as 1 to 3 mg/l in winter, to summertime averages of several hundred mg/l, and summertime peaks of up to 2000 mg/l.

Sewage also contains suspended solids. The suspended solids concentrations that discharge of raw sewage from the study communities would cause in the study rivers was estimated. In twelve locations, it was found that discharges of raw sewage would add to minimum background levels by less than one percent over the entire width of the stream, an immeasurably small change. At Inuvik, the minimum concentration would double, from 1 to 2 mg/l. In view of summertime characteristics, it is considered that this potential change is not significant.

A further check of potential changes in suspended solids concentration was made, assuming mixing of the sewage stream with only one percent of the minimum flow in the fronting river. Under this assumption, it was found that sewage discharges from Inuvik would cause a significant increase in suspended solids concentration over a limited area.

4. Nutrients

Phosphate and nitrogen in fresh water bodies stimulate growth of aquatic plants and algae. Excessive proliferation of algae can render waters uninhabitable by fish.

The contributions of these nutrients that discharge of sewage from study communities would add to the rivers were estimated. Generally, sewage discharge would change average background levels by less than one percent, except in the case of Inuvik, where the change would be in the range of

ten to fifty percent. Inuvik's location, a short distance upstream of the mouth of East Channel, at the Beaufort Sea, tends to minimize the importance or liklihood of algae growth downstream of Inuvik. The increase in concentrations of nutrients in the study rivers which could result from discharge of sewage from the study communities is not considered to be significant.

5. Dissolved Solids

Natural surface waters normally contain a variety of anions and cations, such as calcium, magnesium, sodium and chloride. Domestic sewage contains relatively high concentrations of common ions, so the net effect of sewage discharges commonly is to increase the total dissolved solids concentration in the receiving water.

The increases in concentrations of total dissolved solids that sewage discharges from study communities would cause in study rivers were estimated. It was found that in twelve locations, average background levels across the stream would increase by less than one percent. At Inuvik, average concentrations would change by about 2 percent, which might cause remotely significant effects over a limited area.

CONCLUSIONS

It was concluded that the effects that discharge of raw sewage from ten of the thirteen study communities could have on the Liard, Peel and Mackenzie Rivers, at forecast year - 2000 populations, were small, often immeasurably so. Effects which could be remotely significant over limited zones could occur below Fort McPherson and Aklavik, and effects below Inuvik would probably be significant. The potential for transfer of water-borne diseases to causal users (those taking water directly

from one of the rivers, and not boiling it or disinfecting it with chlorine tablets) would be increased somewhat above current background levels, throughout all affected river reaches. However, the rivers would be expected to remain safe sources for public water supplies, and treatment requirements would remain fairly simple and basic.

A complete list of conclusions and recommendations are found on pages 6-1 and 6-2 of the Report.

Associated Engineering Services Limited
July, 1978

ASSOCIATED ENGINEERING SERVICES LTD

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Cover Illustration: Adapted from Canadian Hydrographic Services Chart 6417, Mackenzie River, Mile 500 to Mile 530. (Chart courtesy of Northern Transportation Company Limited, Captain Kirkland.)

1. INTRODUCTION

1.1 General

At the present time there are 62 communities in the Northwest Territories having a population of 50 or more people. Seven of these are incorporated as cities, towns or villages, while the remaining 55 are classified as hamlets, settlements and unorganized communities. The incorporated centres generally are the larger, more prosperous and more developed, and have populations ranging from about 1000 to about 10,000. Among the unincorporated communities, only one has a population larger than 1,000, and more than half are smaller than 350. Few have significant potential tax base.

One of the responsiblities of the Government of the Northwest Territories is to provide communities within the NWT with adequate facilities to obtain and treat potable water, and to treat and dispose of domestic sewage. This programme is administered by the Municipal Affairs Division of the Department of Local Government. In many population centres, the most pressing problem has been a shortage of drinkable water, either in winter or in summer. Since its establishment in 1967, the Government has been making a substantial effort to develop reliable supplies of good water, as well as to improve methods of water distribution, waste collection and waste management.

Piped water and sewage services are usual in communities larger than 1,000. However, they are the rare exception in the remainder, which includes most of the unincorporated ones. In almost fifty locations, water is delivered by truck. In truck-serviced communities, virtually all toilet waste was, until recently, collected in honey bags, with other household wastewater being discharged onto the ground. Honey bags are handled and disposed of as solid waste. Therefore, it has only been since the installation of sewage pumpout tanks under new buildings, which began about 1973, that liquid sewage has been collected in truck-serviced communities, and the question of wastewater treatment and disposal has arisen. Improvements in community water supplies and the provision of houses having internal pressure water systems and complete plumbing are expected to result in a sharp increase in water use and wastewater generation in truck-serviced communities, over the next few years.

In communities having piped services, arrangements for the treatment and disposal of sewage include, for example, lagoons at Hay River, Yellowknife, Pine Point and Inuvik, and direct discharge to the Mackenzie River at Fort Simpson and Norman Wells. In truck-serviced communities the problem of dealing with liquid sewage is relatively new, and arrangements vary, often taking the form of a holding pit.

The Government of the NWT recognizes the need to develop criteria for the satisfactory treatment and disposal of sewage from NWT communities. Nearly all of those are located on large rivers, large lakes or the ocean, so it is foreseen that the ultimate point of disposal for liquid waste will in many cases be a large natural water body. Therefore, the Government wishes to ascertain to what extent public health and aquatic environments might be endangered by discharge of wastewater. Fundamental to consideration of this question is recognition of the fact that risk to public health can never be eliminated; it can only be reduced to levels which are considered to be tolerable. Equally important is recognition that great dilution and natural biological processes enable natural water bodies to assimilate some quantities of domestic (though not necessarily industrial) wastewater constituents, without undue environmental stress. A final consideration is the Government's responsibility to obtain the greatest benefit for the least expenditure of public monies.

1.2 Terms of Reference

The objectives of the present study are:*

1. To estimate, using published information, what effects sewage from the NWT communities which are located adjacent to large Mackenzie Basin rivers would have on those rivers, under different seasonal conditions.

*Objectives as stated in the Terms of Reference for the Study, contained in AESL proposal to Municipal Affairs Division, December 6, 1977. Nahanni Butte was added later.

2. To use those estimates to determine what effluent criteria would have to be met, at present population centres, in order to,

   (a) protect the river environment from undue stress as measured in various terms, including aesthetic ones, and

   (b) maintain risk to public health at an acceptably low level.

3. In the event that sufficient information to establish rational criteria for any significant parameter is not available at the present time, to state what further information would be needed to accomplish the task.

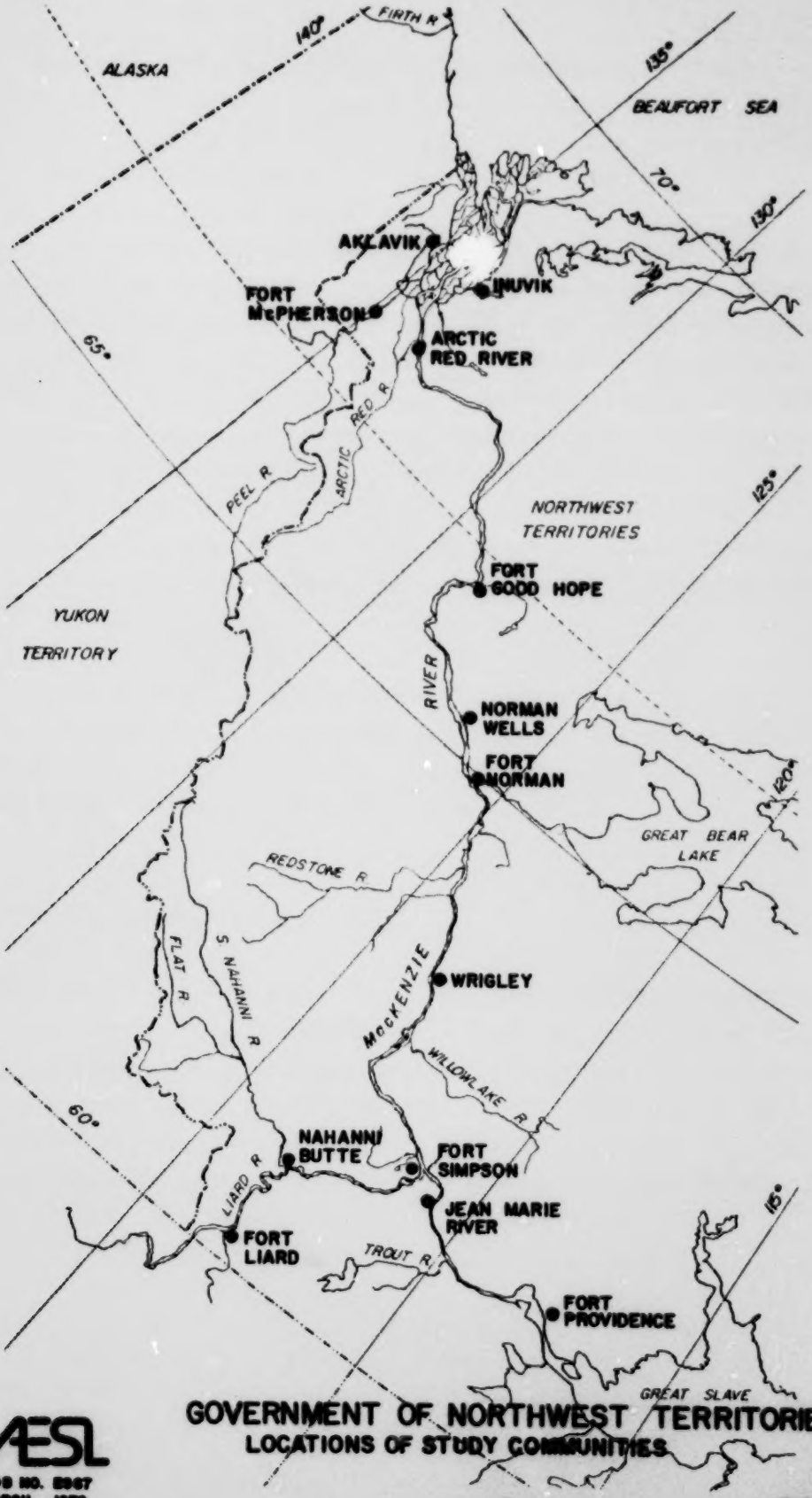
Locations to be considered, to the extent made possible by existence of data, are:

Fort Providence	Mackenzie River
Jean Marie River	Mackenzie River
Fort Simpson	Mackenzie River
Wrigley	Mackenzie River
Fort Norman	Mackenzie River
Norman Wells	Mackenzie River
Fort Good Hope	Mackenzie River
Arctic Red River	Mackenzie River
Aklavik	Mackenzie River (West Channel)
Inuvik	Mackenzie River (East Channel)
Fort McPherson	Peel River
Fort Liard	Liard River
Nahanni Butte	Liard River

The locations of these communities, and their relationship to major rivers are shown in Figure 1-1.

It is emphasized that the report which follows is an engineering review of a public health and environmental question. Its purpose is to provide an assessment of potential wastewater impacts on the Liard, Peel and Mackenzie rivers. The main emphasis is on estimating physical and microbiological changes in water quality, since it is recognized that impacts on the environment and biological activitiy, and public health concerns, will be related to those parameters. Conditions of river flow, river water quality, ice cover and river use have very wide seasonal variations, consequently, the magnitude and significance of wastewater effects also vary widely. In this study, wastewater impacts have been assessed at the combination of least favourable environmental conditions recorded to date, as though those conditions remained static throughout the year. This approach is much simpler than an attempt to model the interaction of wastewater with the river environment over, say, a complete annual cycle, and should yield a conservative upper bound on the magnitude of the effects considered.

It is also emphasized that the study considers only municipal wastewater of essentially domestic character. Wastes from the oil refinery at Norman Wells are not discharged into the municipal sewerage system, and there are, at present, no other waste-producing industrial installation of significance in any of the communities included in the study. Nor is the construction of such installations in any of these communities foreseen at this time.



AESL

JOB NO. 8867
MARCH, 1978

GOVERNMENT OF NORTHWEST TERRITORIES
LOCATIONS OF STUDY COMMUNITIES

FIGURE 1-1

2. NORTHWEST TERRITORIES PORTION OF THE MACKENZIE RIVER BASIN

2.1 River and Tributaries

The Mackenzie is the eighth largest river system in the world, and is the second largest in North America, being exceeded in length and drainage area only by the Mississippi. Its basin encompasses one third each of British Columbia and the Yukon Territory, two thirds of Alberta, one fifth of Saskatchewan, and the western quarter of the Northwest Territories, a total of nearly 1.8 million km^2 (700,000 square miles). The Mackenzie River itself flows approximately 1600 km (1000 miles) from its source in the west arm of Great Slave Lake, to the Beaufort Sea. Its average width is about 1.3 km (1 mile), and its average gradient about 1 in 10,000 (0.5 feet per mile). Flows vary widely between winter and summer, but average around 14,000 m^3/sec (500,000 cfs).

The Liard River is one of the system's main tributaries. It originates deep in the southern Yukon, passes through the northeast corner of British Columbia, and flows about 350 km (220 Miles) from the junction of the BC, Yukon and NWT borders before joining the Mackenzie at Fort Simpson.

2.2 Basin Characteristics

The Mackenzie Valley is a lowland extending from the Central Plains region to the Arctic Ocean. It is bounded on the west by the cordillera of the Mackenzie and Richardson Mountains, and on the east by the exposed crystalline and metamorphic rock of the Canadian Shield. In the valley itself, thick glacial and alluvial deposits overlie Paleozoic sedimentary bedrock. The valley narrows toward the north, finally opening into an extensive delta.

The climate of the Mackenzie Valley is classified as subarctic continental, characterized by low annual precipitation (25-35 cm), extended cold winters, and warm summers. Winter normally arrives in mid-September, and, with the cessation of surface runoff, flows in the river system decline. Ice forms, and attains thicknesses of 1.2 to 1.5 m by late winter. Annual minimum temperatures throughout the region normally are less than -45°C.

Warm weather returns in the month of May. Melting of snow and flash runoff over frozen ground result in a rapid rise in flows and river level, which lifts the ice. The ice breaks up, and is carried north, through the Delta, to the Beaufort Sea. There are particular places along the river where ice jams often occur, resulting in temporary backing up of the river, and flooding. In the Delta itself, for example, the spring flood may be as much as 7 m above winter water levels, but the rise most often is in the range of 3 to 5.5 m.

In winter, Mackenzie River water is clear. Although it is slightly hard, it is of excellent quality for public water supplies. In summer, however, the swift streams from the mountains to the west contribute a heavy load of suspended sediment, and the Mackenzie is turbid below its junction with the Liard. Suspended sediment levels at Inuvik, for instance, average 300-750 mg/l during June, July and August, and may reach peaks of 2000 mg/l.

Except for the northeastern limit of its delta, the Mackenzie Valley is forested. To Fort Norman, principal species include white spruce and balsam poplar on the alluvial flats bordering rivers, and pines, aspen, tamarack and black spruce on slopes and benches. Further north, soil drainage is increasingly impeded by permafrost, and black spruce becomes predominant. Stands of marketable timber are rare further down river than Norman Wells.

The Valley provides habitat for a variety of wildlife, including moose and caribou which are hunted for meat and hides, and a number of small animals which are trapped or hunted for furs. In summer the Delta is the nesting ground of enormous numbers of waterfowl, including geese, swans and ducks.

The river is home to at least 32 species of fish, of which cisco, whitefish, inconnu and char are of importance to commercial fishing and as a food source for residents, and grayling, char and walleye are of importance for sports fishing. Fish are particularly numerous at junctions of major tributaries, which coincides with favoured locations for settlement (1).

Thirteen recognized communities have been established on the banks of the Liard, Mackenzie and Peel Rivers. Various public and private ventures also have camps and facilities in locations adjacent to these rivers, residents have trapping, hunting and fishing camps which are occupied seasonally, and the rivers themselves become shipping channels during the summer months. Large camps established to support resource exploration and public construction projects include oil companies' camps at Bar C, Swimming Point and Farvel in the Mackenzie Delta, the large highway construction camp for the Dempster Highway located near Arctic Red River (now gone), and Hire North's camps for clearing the Mackenzie Highway right-of-way (of which only the one at River Between Two Mountains is still in place). Camps such as these may be in use for a year or two, or much longer, depending upon the duration of the activities which they support. Furthermore, it is not possible to predict where other camps may in future be established, to support projects not yet planned.

Fishing and trapping camps are often occupied by family groups throughout the summer months, and some also serve as overnight stops during wintertime for trappers tending their traplines. Camps are especially numerous in the Mackenzie Delta, where muskrat trapping is an important source of income.

3. COMMUNITY CHARACTERISTICS

3.1 General

The total resident population of the Northwest Territories portion of the Mackenzie Basin is about 30,400. This includes 2810 at Fort Smith on the Slave River, nearly 18,000 divided among eight centres around the shores of Great Slave Lake, 500 on Great Bear Lake, 390 on the Liard River, nearly 8000 on the Mackenzie and Peel Rivers, and a further 800 at small communities in scattered locations.

The locations of communities on the Liard, Mackenzie and Peel rivers are shown in Figure 3.1. All of the communities are quite small with Inuvik, at a 1977 population of 3,100, being by far the largest. Few have identified resources or expectations of economic development which are likely to lead to rapid growth within the twenty year planning horizon for the study. None have expectations of industrial activity likely to alter the character of municipal wastewater.

For each community, basic information relevant to the study is presented below. Populations in 1977 have been taken from population projections for the period 1976-1986 provided by Municipal Affairs Division. Other information is taken from "Community Data, 1974" (2) and the Canada North Almanac, 1977 (3).

3.2 Community Information and Services

3.2.1 Fort Liard

Fort Liard is located on the south bank of the Liard River, immediately upstream of the confluence of the Liard and Petitot Rivers. It is about 80 km downstream from Nelson Forks, B.C., and some 95 km upstream from Nahanni Butte, NWT. The townsite appears to be free of permafrost.

The community's population in 1977 was 297. It was started as a trading post around the beginning of the nineteenth century. Hunting and trapping remain important sources of employment in a scant economy, along with firefighting. Fort Liard has one store, and other facilities include an elementary school, a nursing station, a forestry station and an airstrip. The primary access is by river barge during the summer months, and a winter road is usually constructed from Fort Nelson, B.C.

Amoco operates a gas plant at Pointed Mountain, about 30 km northwest of Fort Liard, and there are some stands of commercial quality timber in the region around the community. Fort Liard will be connected to the road between Fort Nelson, B.C. and Fort simpson, N.W.T., scheduled to be complete about 1983. However, no resource or commercial developments likely to have significant influence on Fort Liard are foreseen at this time.

Water is drawn by hand from the Liard and Petitot Rivers, from private wells, and from two community wells. Sewage is discharged from government-owned and private company buildings to leaching pits. Private dwellings have outhouses (54).

3.2.2 Nahanni Butte

Nahanni Butte is located on the north bank of the Liard River just downstream of the confluence of the Nahanni and Liard Rivers. It is approximately 160 km upstream of Fort Simpson, at the confluence of the Liard and Mackenzie Rivers. This location is within the southern fringe of the discontinuous permafrost zone.

Nahanni Butte's population in 1977 was 93. It is a Slavey Dene settlement having very little wage employment. Facilities provided include a one-room elementary school, a health station and an airstrip. Goods are brought in by river barge in the summer. The community is located at the entrance to Nahanni National Park, and four tourist cabins are made available in summer. Apart from some tourism potential, no resource or commercial developments likely to affect Nahanni Butte are foreseen.

Water is provided from a well at the school, and is also taken by hand from the Liard River. Sewage from the school is discharged into a leaching pit; private homes have outhouses.

3.2.3 Fort Providence

Fort Providence is located on the east bank of the Mackenzie River, 65 km downstream from the river's exit from Great Slave Lake, and 187 km upstream from Jean Marie River. It is within the zone of discontinuous permafrost.

The population of Fort Providence in 1977 was 614. A trading post was operated intermittently at or near the present townsite between 1786 and 1820, and a permanent mission was established in 1861. Fort Providence is now on the Mackenzie Highway system, and tourism is an important aspect of its economy. Commercial establishments include two general stores, a handicraft shop, two or three service stations, and two motels. Facilities provided include a school, a nursing station and an airstrip. About half of the labour force of 200 is employed full time. No resource or economic developments likely to have a significant effect on Fort Providence are currently foreseen.

Water is drawn through a permanent intake in the Mackenzie River and filtered and chlorinated before being distributed by tank truck. Sewage is collected by tank truck and discharged into a large dugout lagoon, located 1-2 km inland from the townsite. The lagoon has no planned outlet and it is believed that any effluent must pass over a considerable distance of fairly level wooded terrain before reaching the Mackenzie River or any tributary stream. Soils a few feet below the surface in the townsite area have extremely low permeability and it is believed that similar conditions exist at the lagoon.

3.2.4 Jean Marie River

Jean Marie River is located on the west bank of the Mackenzie River, at the junction of the Jean Marie and Mackenzie Rivers. It is 187 km downstream from Fort Providence and 68 km upstream from Fort Simpson. It is within the southern fringe of the discontinuous permafrost zone.

Jean Marie River's population in 1977 was 58. It is a Slavey Dene community having a primary school and an airstrip. There are stands of commercial grade timber in the region around the townsite, and the community co-operative operates a small sawmill. There is also some hunting, trapping and fishing. No resource or commercial developments likely to affect Jean Marie River are foreseen at this time.

Water is obtained from a community well and from a well in the school, and probably from the rivers as well. Toilets from the school discharge into a small tile field. Other buildings have outhouses.

3.2.5 Fort Simpson

The Village of Fort Simpson occupies an island located near the west bank of the Mackenzie River, just downstream of the confluence of the Mackenzie and Liard Rivers. The island is connected to the mainland by a causeway. Along the Mackenzie, Fort Simpson is 68 km downstream from Jean Marie River, and is 237 km upstream of Wrigley. It is also 160 km downstream from Nahanni Butte, along the Liard. The subsurface soils on the island are silty sands. Permafrost occurs sporadically.

Fort Simpson's population in 1977 was 1,144. It was founded about 1804 as a trading post. Being at the confluence of two great navigable waterways, it has grown as a commercial, administrative and service centre, serving a wide area. It is now the northern terminus of the Mackenzie Highway, and is a centre for resource exploration. Fort Simpson has several stores, and a variety of commercial ventures offering services related to transportation, construction and exploration. The developed townsite now occupies most of the island, and will soon spread onto the mainland. However, no potential resource or commercial developments which would have a significant effect on Fort Simpson's growth are known at this time.

Water is drawn from an intake positioned near the east side of the Mackenzie River, an arrangement which avoids the siltier water contributed by the Liard River. Water is filtered and chlorinated and may be treated by coagulation during the summer months. The water distribution and sewage collection systems are piped and of fairly conventional underground design. Sewage is discharged into the Mackenzie River below low water level, without prior treatment, at a point near the north (downstream) end of the island.

3.2.6 Wrigley

Wrigley is located on a high bench which forms the east bank of the Mackenzie River, 237 km downstream from Fort Simpson and 253 km upstream of Fort Norman. The townsite is within the zone of discontinuous permafrost.

Wrigley's population in 1977 was 138. The community first grew around a trading post on an island 38 km upstream, in the 1880's, and was moved twice before being finally established at the present location in 1965. The community has one store and a small sawmill, and is provided with an airstrip. As is true of all communities along the Mackenzie River system north of Fort Simpson, goods are shipped to Wrigley annually by barge. No resource or commercial developments likely to cause significant growth in Fort Wrigley are foreseen, although eventual extension of the Mackenzie Highway north from Fort Simpson will probably bring some improvement to the sparse economies of all of the settlements along the Mackenzie River.

Water is supplied from a 90-foot deep well, and is chlorinated before being distributed by tank truck. Most buildings have outhouses.

3.2.7 Fort Norman

Fort Norman is located on the east bank of the Mackenzie River, on the upstream side of the junction of the Bear River. It is 253 km downstream from Wrigley, and 81 km upstream of Norman Wells. This location is well within the zone of discontinuous permafrost.

Fort Norman's population in 1977 was 282. The community was founded as a trading post in 1810. Fort Norman has one store, a hotel, and two small contracting firms offering services in construction and transportation. Hunting, trapping and fishing also contribute to a slight economy. The community is provided with a nursing station, a school and an airstrip. Some coal deposits are known in the region around Fort Norman, and Northern Canada Power Commission has made studies of the hydroelectric potential of the Bear River. Although some resource exploration has operated from Fort Norman in recent years, there are no known developments which would be expected to stimulate rapid growth in the community.

Water is drawn through an intake submerged in the Bear River, and is chlorinated before being distributed by tank truck. Bagged sewage and sewage taken from pumpout tanks is disposed of at the community's nuisance area, located on high ground between the rivers, and some distance from either. Liquid sewage is discharged into a holding pit which is intended not to overflow.

3.2.8 Norman Wells

Norman Wells is located on the east bank of the Mackenzie River, 81 km downstream from Fort Norman and 194 km upstream of Fort Good Hope. Thaw-sensitive permafrost occurs widely in the townsite area.

Norman Wells' population in 1977 was 484. Norman Wells had its beginnings in 1920, when a subsidiary of Imperial Oil successfully developed oil wells from a depth of only 100 feet. Norman Wells is now the site of a small refinery which supplies much of the fuel consumed in the Mackenzie Valley and Western Arctic Islands. The economy of the community is derived from the operation of the refinery; commercial ventures include a hotel, a store and small general contracting firms. Facilities include an airport used by jet passenger aircraft, a small hospital and a school. No expansions of the refinery are expected, and no other developments which would cause rapid growth in Norman Wells are foreseen.

Water is taken from a small reservoir formed by damming Bosworth Creek, which flows into the Mackenzie just beyond the north (downstream) end of the developed townsite. It is not known whether Bosworth Creek will always be able to supply Norman Wells' needs during severe winters, and the Mackenzie River is regarded as a potential alternate source. Norman Wells has piped water and sewage services throughout most of the townsite. The townsite sewerage system collects domestic wastewater from dwellings and from commercial and institutional buildings, but not process waste from the refinery. Wastewater is discharged into the Mackenzie at two or three points; at two of the outfalls it is first passed through a large tank. The outfalls are all upstream of the point where the alternate water intake is located.

3.2.9 Fort Good Hope

Fort Good Hope is located on the east bank of the Mackenzie River, a few km upstream of the junction of the Hare Indian River with the Mackenzie. It is 194 km downstream from Norman Wells, and 345 km upstream of Arctic Red River. This location is nearly within the zone of continuous permafrost.

Fort Good Hope's population in 1977 was 443. The community grew around a trading post which was established in 1805, and hunting, trapping and fishing still form the main basis of the community's slight economy. There is one store and one small general contractor. The settlement is also provided with a school, nursing station and an airstrip. Although there has been some petroleum exploration in the area, there are no developments foreseen which would have a significant impact on Fort Good Hope's economy or size.

Water is supplied by tank truck from small lakes and creeks close to the settlement, and from the Mackenzie River if those sources freeze. At the present time, the Government is investigating alternatives for a permanent water supply facility. Sewage taken from pumpout tanks is discharged into a holding pit some distance from the Mackenzie River, which is intended not to overflow (58).

3.2.10 Arctic Red River

Arctic Red River is located between the Mackenzie River and the Arctic Red River, at the confluence of the two. It is 345 km downstream from Fort Good Hope and 136 km upstream of Inuvik. This location is just within the zone of continuous permafrost.

Arctic Red River's population in 1977 was 132. The permanent community grew around a trading post which was established around 1870. Hunting, trapping and fishing, and the seasonal operation of a small sawmill, provide the basis of the community's meagre economy. Facilities include a primary school and an airstrip. Arctic Red River is located on the Dempster Highway, which will soon link Inuvik with the Yukon Territory's highway system. Use of the townsite as a trucker's rest and fuel stop may stimulate some limited development.

Water is supplied by tank truck from a lake located beside the townsite. Due to the risk of contamination it is probable that an alternate source will have to be sought in the future, and it is possible that the Mackenzie River might be used. Sewage is collected by honeybag and by tank truck. At present it is intended to be discharged in the community's nuisance area (58).

3.2.11 Fort McPherson

Fort McPherson is located on the east bank of the Peel River, 170 km upstream of Aklavik. It is within the zone of continuous permafrost.

Fort McPherson's population in 1977 was 796. The community was founded as a trading post in 1840. It is now located on the completed portion of the Dempster Highway. Hunting, trapping, fishing, highway maintenance and the manufacture of canvas goods are the main sources of its economy. Facilities include a large school, a nursing station and an airstrip. There has been petroleum exploration in the area, but no report of resources which might be developed has been published. Use of Fort McPherson as a service centre for truckers operating on the Dempster Highway may soon provide a new source of employment and economy. In time, development of the gasfields of the Mackenzie Delta and construction of a gas pipeline parallel to the Dempster Highway may stimulate significant, permanent real and economic growth at Fort McPherson.

Water is supplied from a small lake, which is refilled each spring by runoff and by the spring flood of the Peel River. A utilidor system provides piped services to some buildings, but most are served by trucks. It is likely that the piped system will be extended. Currently, sewage collected by the piped system is discharged into a large lake (lagoon) located adjacent to the community. It is likely that the point of discharge may eventually be changed. One alternative is discharge to the Peel River. Sewage taken from pumpout tanks is discharged into a holding pit located in a former shale quarry, a short distance to the south of the community. The holding pit is intended not to overflow (58).

3.2.12 Aklavik

Aklavik is located in the Mackenzie Delta, on the west bank of the West (Peel) Channel. It is 170 km downstream from Fort McPherson, and 80 km upstream of West Channel's entry into the Beaufort Sea. It is within the continuous permafrost zone.

Aklavik's population in 1977 was 797. Aklavik served a trading station and regional administrative centre, until most Government activities were transferred to a more suitable townsite, at Inuvik, in the mid 1950's. Trapping, general contracting and a fur garment industry are the primary bases of a limited economy. Since Inuvik's establishment, Aklavik has been off the mainstream of events in the Mackenzie Delta, and it seems unlikely that anything but slow growth will occur.

Water is taken from a lake in summertime, and from the Peel Channel in winter. It is possible that the Peel might, in time, serve as the water source year round. Water is distributed by tank truck in winter, and by a temporary piped distribution system in summer. Sewage is collected by truck. Liquid sewage taken from pumpout tanks is discharged into a pit located in the community's nuisance ground, which is intended not to discharge (58).

3.2.13 Inuvik

Inuvik is located in the Mackenzie Delta on the east bank of the East Channel. It is 136 km downstream from Arctic Red River, and 140 km upstream from East Channel's entry into the Beaufort Sea. Thaw-sensitive permafrost occurs throughout the townsite area.

Inuvik was planned and constructed by the Federal Government in the mid 1950's so that expanding government establishments could be relocated away from extremely difficult townsite engineering problems at Aklavik. Originally designed for a population of 2,000, and an ultimate maximum of 2,500, Inuvik's present size is about 3,100. Oil exploration and gas discoveries north of Inuvik stimulated rapid growth in the early 1970's, and eventual development of the gasfields will probably result in another boom period. Based on the current schedule for construction of the gas pipeline along the Alaska Highway, this boom could not begin before 1983 or 1984.

Water is supplied from the East Channel in winter, and from lakes in the summer. However, it is likely that East Channel will eventually be the supply year-round. Water treatment in winter would include chlorination and filtration, and coagulation would be brought on stream for summer periods.

Inuvik has piped utilities systems. Sewage is discharged into a lagoon located just north of the developed townsite. The developed area has expanded towards the lagoon to the point where there is no longer an adequate separation between the lagoon and adjacent dwellings. It is likely that at least the southern half of the lagoon will be taken out of service within the next few years.

Sewage is discharged from the north end of the lagoon to East Channel shortly before break-up in the spring, and shortly before freeze-up in the fall.

3.3 Community Services and Wastewater Flows

Water is metered as it is pumped into the piped water distribution systems at Fort Simpson, Norman Wells and Inuvik. Current flow rates at Fort Simpson and Inuvik are, respectively, 216,000(4), and 465,000(5) igd, equivalent to consumption rates of 190 and 155 igcd. The consumption rate at Norman Wells averages 83 igcd, however, this includes the truck serviced portion of the town, and it is estimated that consumption in the pipe-serviced areas is about 100 igcd(6). The piping networks in Inuvik and Norman Wells have virtually no leakage or infiltration, so average daily sewage flows will be approximately equal to average daily water consumption. The same relationship has been assumed for Fort Simpson.

Water consumption rates for these communities are high in relation to data reported for other small, non-industrial North American communities. It seems certain that these rates reflect a substantial amount of waste. The Government is aware that excessive water consumption leads to unduly high capital and operations costs, and will probably take steps to curb wastage over the next few years. For planning purposes, Municipal Affairs Division uses a design water consumption rate of 100 igcd (450 lcd). This rate has been used in predicting sewage flow rates from potential future piped utilities systems.

Aklavik is sufficiently large and sufficiently compact that piped utilities may eventually become more economical than trucked. Fort McPherson has the beginnings of a piped utilities system, and it is possible that this will gradually be extended to serve the entire community. Although Fort Providence is somewhat smaller and more scattered, good soil conditions and road access may in time make piped utilities the most economical choice at this location, too. In the other communities, it appears likely that trucked services will be utilized throughout the planning period.

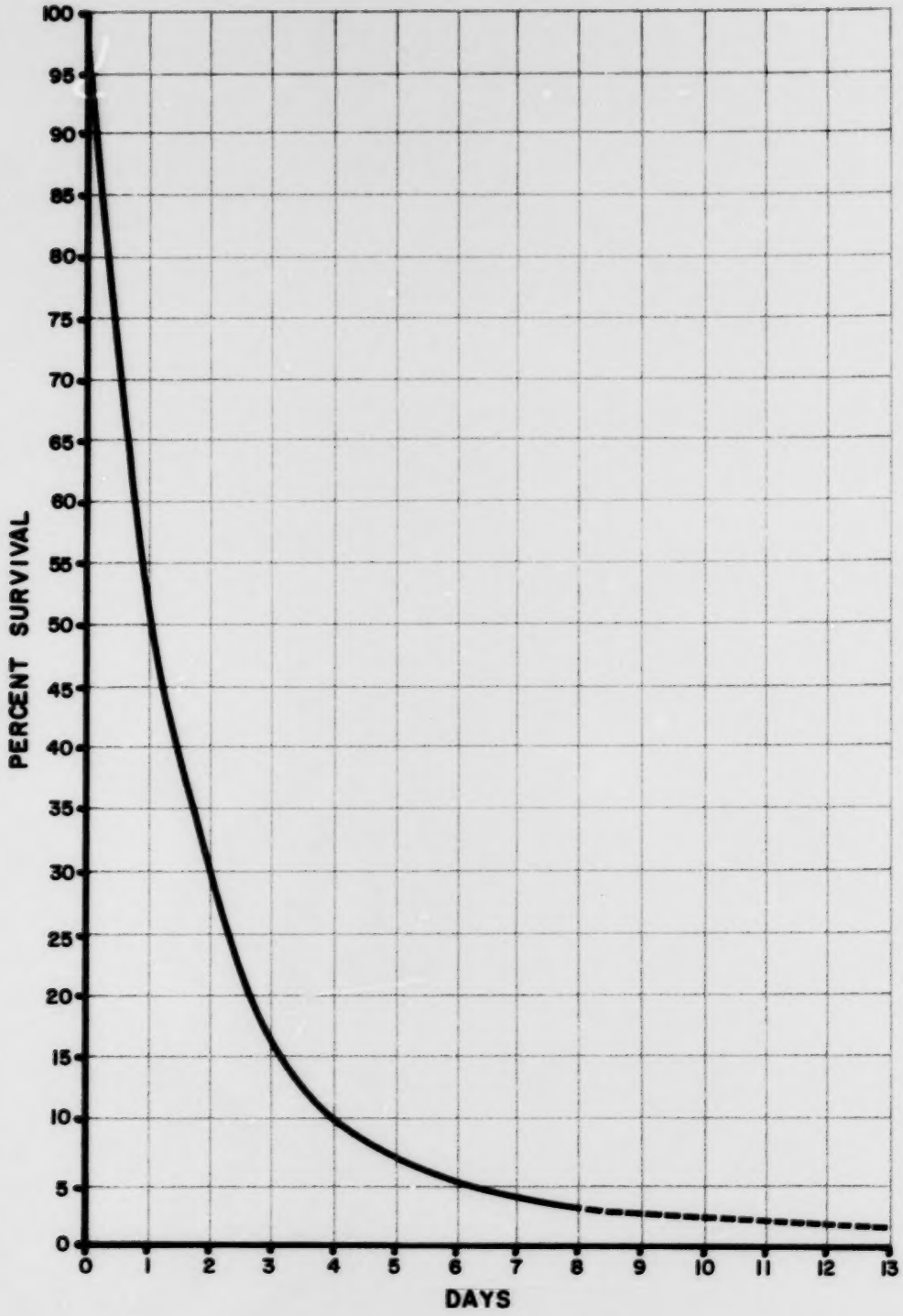
The trucked services system used in the Northwest Territories is undergoing a period of transition, during which the amounts of water delivered and amounts of sewage collected are increasing rapidly. Buildings served by water trucks are equipped with holding tanks, which are filled as necessary (typically, one to three times a week). In older buildings, water is carried from the holding tank to the point of use by hand, in a kettle or bucket; toilet waste is collected in honeybags, and water used in food preparation and washing is discharged onto the ground beside the building. However, most buildings constructed within the last three or four years have been provided with water tanks, complete plumbing and internal pressure systems, and sewage pumpout tanks. This equipment is now standard in truck-serviced areas.

The inconvenience imposed by having to carry water to the point of use by hand keeps water consumption down to 5-15 lcd (1-3 igcd), in older dwellings. However, consumption rates in houses having internal pressure plumbing systems is estimated to average 90 lcd (20 igcd). As the proportion of houses with pressure plumbing grows, water use in truck-serviced communities will increase rapidly. The amount of liquid sewage collected in truck-served communities is also increasing rapidly, toward a design figure in excess of 90 lcd (making allowance for commercial establishments and institutions), from a starting point, in the early 1970's, of little or none at all.

Estimates of the quantiites of sewage to be treated and disposed of from truck-serviced communities have been based on data developed by Municipal Affairs Division. A summary of the water supply and sewage disposal services for each community is given in Table 3-1. The relationship of the thirteen communities under consideration to the Liard, Peel and Mackenzie River, and to each other is shown schematically in Figure 3-1.

TABLE 3-1
COMMUNITY SERVICES, 1978

Community	Water Supply - Source and Treatment	Sewage - Treatment and Disposal
1. Ft. Providence	Mackenzie River. Filtration and chlorination.	Lagoon. No discharge to to Mackenzie River.
2. Jean Marie River	Wells and Mackenzie River. No treatment.	Outhouses.
3. Ft. Simpson	Mackenzie River. Filtration and chlorination.	No treatment. Discharge to Mackenzie River
4. Wrigley	Well source (river not used). Chlorination.	Outhouses.
5. Ft. Norman	Great Bear River. Chlorination.	Storage pit. May discharge to Mackenzie River
6. Norman Wells	Bosworth Creek, with Mackenzie River as backup. Chlorination.	Discharge to Mackenzie River, upstream of back-up water intake.
7. Ft. Good Hope	Small lakes and Mackenzie River. Chlorination.	Storage pit. May discharge to Mackenzie River.
8. Arctic Red River	Lake. Chlorination. May change to Mackenzie River.	Discharge into nuisance ground. May reach Mackenzie River.
9. Inuvik	Mackenzie River East Channel. Chlorination.	Lagoon. Discharge to East Channel, Mackenzie River.
10. Aklavik	Mackenzie River West Channel. Filtration and chlorination.	Storage pit. May discharge to Peel Channel, Mackenzie River.
11. Ft. Liard	Wells and Liard River. No treatment.	Outhouses and leaching pits.
12. Nahanni Butte	Wells. No treatment.	Outhouses.
13. Ft. McPherson	Lake. Coagulation, filtration, and chlorination.	Lagoon. Discharge to Peel River.



GOVERNMENT OF NORTHWEST TERRITORIES

TOTAL AND FECAL COLIFORM SURVIVAL AFTER DISCHARGE TO ICE COVERED RIVER

AESL

JOB NO. E867
MARCH, 1978

FIGURE 5-1

3.4 Population Forecast

Population projections covering the period 1976 to 1986 were provided by Municipal Affairs Division for each of the thirteen communities under consideration. These projections were extended to the year 2000, using the average annual growth rate extracted from the 1976-1986 data, for each community except Inuvik. Inuvik's growth could be accelerated during the mid-1980's if development of the Mackenzie Delta gasfields proceeds, so a special projection taking that possibility into account was prepared. Population forecasts at five year intervals for the period 1978-2000 are shown in Table 3-2.

TABLE 3-2
POPULATION FORECASTS, 1976-2000

Location	Population						
	1976	1980	1985	1990	1995	2000	Growth Rate % Per Year
Fort Providence	605	649	695	749	809	873	1.54
Jean Marie River	56	65	72	83	95	109	2.83
Fort Simpson	1121	1200	1282	1372	1474	1585	1.45
Wrigley	136	150	158	171	185	201	1.64
Fort Norman	277	300	320	343	371	400	1.55
Norman Wells	464	543	659	797	968	1174	3.94
Fort Good Hope	437	467	501	541	584	630	1.54
Arctic Red River	129	139	151	167	183	200	1.85
Inuvik	3400	3707	4915	5947	6847	7993	varies
Aklavik	779	852	941	1034	1144	1267	2.05
Fort Liard	292	316	339	372	405	442	1.74
Nahanni Butte	90	103	113	127	143	162	2.48
Fort McPherson	785	837	900	967	1041	1122	1.50

3.5 Pollutant Quantities

Per capita sewage flows in the north vary widely. In the south, domestic residential flow rates are normally in the range of 0.3 to 0.4 m^3/day (40 to 90 igd) per capita, but in the north flows can either be very low, where vehicles are used to deliver water and collect sewage, or very high, where taps are kept running during the winter to prevent freezing in water and sewage pipes. A per capita sewage flow rate of 2.5 m^3/day (540 igd) was reported for Ketchikan, Alaska (7). This illustrates the difficulty of predicting sewage flow rates for the communities under consideration.

A more direct method of assessing potential pollutants is to simply consider the per capita contribution of pollutant. Per capita quantities of coliforms, five-day biochemical oxygen demand (BOD_5),* suspended solids, and other pollution parameters are quite well known, or can be calculated from a knowledge of their concentrations in a "normal" domestic sewage. We have attempted to use realistic average per capita values, although the values used in sewage treatment plant design are normally higher than actual values. For example, the standard design value for BOD_5 is 75 gm/cap-day (0.17 lb/cap-day)(10), whereas actual measured values in household waste water are closer to 45 gm/cap-day (0.10 lb/cap-day)(9). The reasons for the use of higher design values are to give a factor of safety that will ensure the good operation of the treatment plant under all conditions and to include some non-domestic contribution.

The use of realistic average per capita pollutant contributions is believed justified since, as is explained later in the report, potential pollution impacts are assessed with respect to lowest recorded river flows, thus ensuring that minimum dilutions are considered.

*Biochemical Oxygen Demand (BOD) is the amount of oxygen required by organisms while stabilizing decomposable organic matter under aerobic conditions in the absence of light. The 5-day, 20°C test (BOD_5) is a standard measure of wastewater "strength".

Per capita quantities of the most important and sensitive constituents of domestic sewage are given in Table 3-3. By multiplying these quantities by the year 2000 populations of the communities under consideration, total pollutant quantities associated with each community can be estimated for a time about 20 years hence. These quantities are given in Table 3-4.*

TABLE 3-3

PER CAPITA POLLUTANT QUANTITIES*

Parameter	Daily Per Capita Production
Total coliforms[a]	100×10^9 organisms
Fecal coliforms	95×10^9 organisms
Five-day BOD (BOD_5)	45 grams
Suspended solids (SS)	48 grams
Total phosphate (P)[b]	2.3 grams
Total Kjeldahl nitrogen (N)	12 grams
Total dissolved solids (TDS)	130 grams

(a) Per capita quantities of total coliforms have been reported in the range of two billion to one thousand billion in household waste water (8,9,10). A value of one hundred billion is thought to be a representative average for total coliforms, of which approximately 95 percent would be fecal (11).

(b) Values of about 3.8 gm/cap day of total phosphorous (0.008 lb/cap-day) have been reported (9), but the use of low-phosphate detergents as stipulated in the Canada Water Act of 1970, has reduced this value by about 40 percent.

*This study considers only the types of wastes generated in non-industrial communities. It does not consider wastes from mining, industrial or manufacturing processes.

TABLE 3-4

POLLUTANT QUANTITIES ASSOCIATED WITH EACH COMMUNITY IN THE YEAR 2000

Community and Year 2000 Population	Daily Pollutant Quantity (Kilograms)[a] Coliforms (10^9)						
	Total	Fecal	BOD_5	SS	P	N	TDS
Ft. Providence (873)	87,300	82,900	39.3	41.9	2.0	10.5	113.5
Jean Marie R (109)	10,900	10,400	4.9	5.2	0.3	1.3	14.2
Ft. Simpson (1,585)	158,500	150,600	71.3	76.1	3.6	19.0	206.1
Wrigley (201)	20,100	19,100	9.0	9.6	0.5	2.4	26.1
Ft. Norman (400)	40,000	38,000	18.0	19.2	0.9	4.8	52.0
Norman Wells (1,174)	117,400	111,500	52.8	56.4	2.7	14.1	152.6
Ft. Good Hope (630)	63,000	59,900	28.4	30.2	1.4	7.6	81.9
Arctic Red R. (200)	20,000	19,000	9.0	9.6	0.5	2.4	26.0
Inuvik (6,700)	670,000	636,500	301.5	321.6	15.4	80.4	871.0
Aklavik (1,267)	126,700	120,400	57.0	60.8	2.9	15.2	164.7
Ft. Liard (442)	44,200	42,000	19.9	21.2	1.0	5.3	57.5
Nahanni Butte (162)	16,200	15,400	7.3	7.8	0.4	1.9	21.1
Ft. McPherson (1,122)	112,200	106,600	50.5	53.9	2.6	13.5	145.9

(a) Except coliforms, which are given as billions (10^9) of organisms.

4. RIVER CHARACTERISTICS

4.1 General

Northern rivers in general are characterized by wide seasonal variations in flow rate and water quality. During winter, low flows occur due to freezing of watersheds; many small rivers and tributary streams freeze right to the bottom. In large rivers, the water flowing beneath the ice is generally clear and has a relatively low concentration of dissolved oxygen (12, 13, 14, 15, 16, 17, 18). After spring thaw, flows increase tremendously and large quantities of suspended sediment are washed downstream. In the Mackenzie, Liard, and Peel Rivers, the flows during June and July are generally the highest of the year. Maximum flows may be 5 to 25 times higher than the minimum flows, which occur during March and April.

Eutrophication is a natural aging process of lakes and rivers that can be accelerated by the addition nutrients such as phosphorous and nitrogen. However, northern lakes and rivers are young relative to eutrophication, and generally are poor in nutrients. Concentrations of phosphorous that could cause algal blooms in southern lakes would not be expected to have this effect on arctic lakes (12).

As a consequence of the low nutrient concentrations, coupled with low temperatures, chemical and biological activity in Mackenzie Basin rivers is low. Fish growth rates are low (19).

4.2 River Uses

At the present time, the Mackenzie, Liard, and Peel Rivers are used primarily as a habitat for fish, wildlife, and waterfowl, as domestic water supplies, and as transporation routes. Additional or potential uses include recreation, industrial water supply, generation of hydro-electric power, stock watering,

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and crop irrigation. This discussion of river uses is limited to the two important and most critical ones; domestic water supply and fish habitat. If water quality is maintained at a satisfactory level for these two uses, all other uses will be protected.

4.2.1 Domestic Water Supply

Many of the communities in the Mackenzie basin, as discussed in Chapter 3, use river water for domestic purposes. In general, to be suitable for domestic purposes the raw water supply must be of such quality that the Canadian Drinking Water Standards and Objectives (20) can be acheived by normal water treatment technology, ie. coagulation, sedimentation, filtration, and chlorination. One general objective of wastewater management is that drinking water standards and objectives be exceeded only as a result of characteristics of the natural water, and not as a result of sewage discharges.

4.2.2 Fish Habitat

Fishing is very important throughout the basin, as a major source of food to the native population, and as a recreational activity. The domestic fish harvest for the Mackenzie River in 1972 was estimated to be approximately 825,000 pounds (21).

Fish that spend the entire year in Mackenzie Basin rivers and streams must be able to survive the reduced dissolved oxygen levels and temperatures near 0°C that occur in ice-covered rivers in the winter, and the high sediment levels and tremendous scouring of the river beds that occur in the spring.

Thirty-four species of fish have been identified in the Mackenzie River system. The most important in terms of abundance are Arctic Grayling, Arctic Char, Inconnu, Humpback and Broad Whitefish, Least and Arctic Cisco, Northern Pike, and Longnose Sucker. Major fish runs occur just after ice breakup and just before freezeup. The periods of high biological sensitivity to pollution are

considered to be May 15 to June 30, and September 15 to November 15. These periods coincide with high river flows, and therefore with extremely high dilution and high assimilative capacity. Wastewater loadings which would be acceptable under the critical winter low flow conditions would not likely be dangerous to fish runs or fish spawning cycles.

4.3 River Flows

The least dispersion and dilution of a waste stream entering a river occurs when the flow in the river is at its lowest. Flow data for the Mackenzie, Liard and Peel Rivers were obtained from the Water Survey of Canada, Water Resources Branch, Department of the Environment (22, 23, 24, 25, 26, 27). Flow is measured at or near eight of the thirteen communities under consideration. The extreme minimum daily discharge measured during the period of record at each of those locations is presented in Table 4-1. Also shown in Table 4-1 are estimated extreme minimum daily flows at the remaining five communities. Estimates have been derived by adjusting the minimum flow recorded at the nearest station upstream by the minimum expected inflow over the intervening reach.

In northern rivers, minimum flows normally occur towards the end or March, under ice cover. Ice usually starts to form on the Mackenzie, Peel and Liard Rivers towards the end of October. Flow declines throughout the fall and winter periods, but water levels in the channels stay about the same once ice formation starts (28, 29). As the winter progresses, the ice becomes thicker, reaching an ultimate thickness of 90 to 150 cm (23).

Flow velocities are very much reduced under the ice cover (28, 29). The significant size scale of the turbulent eddies are reduced, with the effect that the river's diffusion potential is less (30). Therefore, the distance over which an equal degree of mixing is achieved will be much greater for flow under ice than for the corresponding open channel case.

In summary, a northern river's winter regime is its most critical for dilution of incoming waste streams, because of the reduction of both flow and mixing potential. Throughout the analysis which follows, wastewater impacts have been assessed for winter low flow conditions.

TABLE 4-1
RIVER FLOWS

River	Community	Minimum Recorded Discharge Rate, Qmin (m^3/sec)
Mackenzie	Fort Providence	1036
Mackenzie	Jean Marie River	1132 (E)*
Mackenzie	Fort Simpson	1523
Mackenzie	Wrigley	1588 (E)
Mackenzie	Fort Norman	1653 (E)
Mackenzie	Norman Wells	2111
Mackenzie	Fort Good Hope	2174 (E)
Mackenzie	Arctic Red River	2236
Mackenzie	Aklavik	69
Mackenzie	Inuvik	3
Liard	Fort Liard	172
Liard	Nahanni Butte	212 (E)
Peel	Fort Macpherson	45

*E - Estimated

An important consideration in predicting downstream effects of sewage discharges is the time it takes for a given discharge to reach some critical area, such as the location of a water supply intake. Canadian Hydrograph Service Charts of the Mackenzie and Peel Rivers are available, and were consulted to determine the average river velocities between communities. Estimates of maximum and minimum river velocities were made, based on stage-discharge relationships obtained from Water Survey of Canada. These estimates, together with corresponding maximum and minimum water travel times, are given in Table 4-2. Travel times are given only to the next immediate downstream community, based on the assumption that potential pollutional effects from a given community will be greatest for the closest downstream community.

TABLE 4-2
RIVER VELOCITIES

Communities		Distance	River Velocities (m/sec)		Travel time (hours)	
Upstream	Downstream	Apart(km)	Minimum	Maximum	Minimum	Maximum
Ft. Providence	Jean Marie R	187	0.5	1.4	37	104
Jean Marie R.	Ft. Simpson	69	0.5	1.4	14	38
Ft. Liard	Nahanni Butte	95	0.34	2.0	13	78
Nahanni Butte	Ft. Simpson	160	0.34	2.0	22	131
Ft. Simpson	Wrigley	237	0.5	1.4	47	132
Wrigley	Ft. Norman	253	0.5	1.4	50	141
Ft. Norman	Norman Wells	81	0.5	1.4	16	45
Norman Wells	Ft. Good Hope	194	0.5	1.4	38	108
Ft. Good Hope	Arctic Red R	345	0.5	1.4	68	192
Arctic Red R	Inuvik	137	0.06	0.4	95	634
Ft. McPherson	Aklavik*	170	0.12	0.65	73	394

*Aklavik will essentially receive only Peel River water.

4.4 River Water Quality

In general, the water quality in the Mackenzie, Peel, and Liard Rivers is very good, although there are large natural variations in quality due to winter ice cover and high spring runoff. Quality changes also occur as major tributaries contribute water of different characteristics. The Inland Water Directorate of Environment Canada has carried out a water quality sampling progam in the Northwest Territories since 1960, and has stored the data collected in a computerized water quality data bank (NAQUADAT) which covers all of Canada. They have also published data relating to a large number of water quality parameters (31). Measured values of dissolved oxygen, suspended solids, phosphorous, nitrogen, and total dissolved solids are presented below in Table 4-3. These parameters were chosen for consideration because they are closely related to potential changes due to sewage discharges. The most sensitive indicator of sewage, coliform concentration, is not presented in the NAQUADAT data. It can be seen that the minimum dissolved oxygen (DO) values measured vary from 4.9 to 16.0 mg/l. However, at many stations, samples were not taken during ice cover, and therefore the minima do not represent winter conditions. Winter DO's under the ice can drop naturally to about 5 mg/l (31).

In order to determine whether any detectable water quality change has resulted from Inuvik's effluent discharge, a careful evaluation has been made of all potential sewage-related parameters reported at the NAQUADAT stations upstream and downstream of Inuvik. Inuvik was chosen because it is the largest community of those being considered, and because the flow in the East Channel of the Mackenzie River at Inuvik is lower than the lowest river flow recorded for any of the other communities under consideration. Thus, the dilution of Inuvik's wastewater is far less than that of any of the other communities. It must be noted, however, that Inuvik's lagoon outfall is opened only at certain times of the year, and it may be that sampling schedules have so far coincided only with no-discharge periods. The question is further complicated by whatever pollutants may be carried into the river by runoff from the townsite area.

Data are presented in Table 4-4 for twelve water quality parameters at four different monitoring stations; one upstream of Inuvik, one at Inuvik (above the sewage outfall), and two downstream of Inuvik. The average percent changes in these parameters at the two downstream stations, relative to concentrations at the upstream station, are presented in Table 4-5. It is apparent that the average concentration of most dissolved and suspended solids increase after passing Invuik, although the average dissolved oxygen level also increases. The general trend toward increase concentrations of dissolved materials is probably predominantly natural, and unrelated to Inuvik's sewage effluent discharge, although there are insufficient data to draw strong conclusions either way. Such factors as sampling within or outside the waste discharge plume, changing river flow rates, and the collection, in some cases, of relatively few samples tend to make any interpretation of available data somewhat suspect.

TABLE 4-3
WATER QUALITY MONITORING DATA

NAQUADAT Station # (abbrev.)	Station Locations	Measured Values of Selected Parameters, mg/l				
		Minimum DO[a]	Minimum SS[a]	Average Phosphate[b]	Average Nitrogen[b]	Average TDS[b]
FB1	Mackenzie R above Ft. Providence	6.2 (15)	<1 (41)	0.016 (26)	0.5 (21)	131 (36)
FB5	Mackenzie R just above juntion with Liard R	5.5 (23)	2 (26)	-	-	-
GC1	Mackenzie R above Ft. Simpson	9.8 (2)	<1 (19)	0.028 (21)	0.6 (17)	127 (28)
HC1	Mackenzie R above Wrigley	12.4 (2)	3 (14)	0.07 (19)	0.7 (18)	163 (18)
KA3	Mackenzie R 20 mi upstream from Norman Wells	7.4 (1)	3 (17)	-	-	-
KA2	Mackenzie R 14.5 mi above Norman Wells	9.6 (2)	2 (13)	0.104 (20)	0.6 (17)	146 (16)
KA1	Mackenzie R. at Norman Wells	-	2 (48)	0.029 (22)	-	124 (103)
LB2	Mackenzie R. 2.5 mi above Ft. Good Hope	11.6 (2)	2 (12)	0.14 (18)	0.6 (16)	139 (16)
LD1	Mackenzie R at Ft. Good Hope	-	29 (4)	0.029 (1)	<0.5 (1)	136 (8)
LA3	Mackenzie R 0.75 mi above IHD Station at Arctic Red R	8.8 (8)	<1 (38)	0.064 (34)	0.6 (19)	157 (72)
LC12	Mackenzie R. East Channel, above Inuvik	5.1 (15)	<1 (15)	-	-	-
LC6	Mackenzie R. East Channel, at Inuvik	10.3 (4)	26 (4)	-	-	-
LC11	Mackenzie R East Channel, below Inuvik	4.9 (15)	<1 (16)	-	-	-
LC10	Mackenzie R East Channel, below Inuvik	5.7 (7)	<1 (9)	-	-	-
MC4	Mackenzie R West Channel, below Aklavik	9.8 (3)	58 (3)	-	-	-
ED1	Liard R at Ft. Liard	6.0 (7)	1 (24)	0.007 (2)	-	76 (42)
ED5	Liard R 8.5 mi below Ft. Liard	16.0 (1)	<1 (14)	0.109 (19)	0.8 (18)	142 (16)
ED2	Liard R above Ft. Simpson	10.8 (2)	<1 (11)	0.137 (25)	0.7 (19)	157 (26)
ED7	Liard R just above junction with Mackenzie R	5.0 (20)	<1 (28)	-	-	-
MC1	Peel R above Ft. McPherson	5.0 (7)	<1 (21)	0.007 (1)	-	156 (9)
MC2	Peel R at Ft. McPherson	11.1 (2)	3 912)	0.21 (21)	0.7 (18)	161 (17)

a Minimum dissolved oxygen and suspended solids concentrations are given because these minima occur during the winter, when they are most likely to be affected by sewage discharges. The number of samples taken is shown in brackets.

b Average values of Total Phosphate and Total Kjeldahl Nitrogen are given because eutrophication depends on average nutrient concentrations and is generally unaffected by peak concentrations. The number of samples taken is shown in brackets. Average total dissolved solids values are given because the variation in TDS is relatively small.

TABLE 4-4

WATER QUALITY DATA UPSTREAM AND DOWNSTREAM OF INUVIK

	Parameter[a]	Value	Concentration (mg/l)[b] LC12 (upstream)	LC6 (at Inuvik)	LC11 (downstream)	LC10 (downstream)
1.	pH	low	7.1	7.8	7.5	7.6
		high	8.0	8.0	8.1	8.1
		average	7.7	7.9	7.8	7.9
2.	Specific Conductance	low	78	78	130	100
		high	500	195	350	350
		average	227	157	253	218
3.	Total Hardness	low	86.2	90.0	86.2	94.5
		high	152.5	109.4	183.1	151.3
		average	120.6	100.3	129.0	129.4
4.	Suspended Solids	low	< 1	26	< 1	< 1
	(Non-filtrable	high	447	346	729	655
	residue)	average	86	131	117	99
5.	Dissolved Oxygen	low	5.1	10.3	4.9	5.7
		high	14.7	15.0	15.6	13.7
		average	11.2	12.2	12.0	11.4
6.	Dissolved Nitrogen	low	0.0	0.0	0.0	0.0
		high	0.54	0.28	0.46	0.49
		average	0.29	0.17	0.28	0.29
7.	Total Dissolved	low	0.0	0.0	0.0	0.0
	Phosphorous	high	0.046	0.026	0.049	0.064
		average	0.017	0.012	0.017	0.019
8.	Dissolved Sodium	low	0.43	4.3	4.3	4.6
		high	10.7	5.8	44.6	11.3
		average	7.7	5.1	10.2	8.5
9.	Dissolved Chloride	low	3.2	6.7	3.8	4.4
		high	16.2	8.6	21.5	18.1
		average	10.4	7.7	11.5	11.6

TABLE 4-4

WATER QUALITY DATA UPSTREAM AND DOWNSTREAM OF INUVIK

Parameter[a]	Value	Concentration (mg/l)[b] LC12 (upstream)	LC6 (at Inuvik)	LC11 (downstream)	LC10 (downstream)
10. Dissolved Sulphate	low	13.7	21.0	20.3	22.7
	high	37.9	28.5	50.5	38.7
	average	28.5	24.9	33.0	31.6
11. Dissolved Iron	low	0.04	-	0.023	< 0.05
	high	0.23	-	4.42	0.11
	average	0.08	-	0.48	0.07
12. Dissolved Potassium	low	0.9	0.9	1.0	1.0
	high	1.7	1.0	1.9	1.6
	average	1.2	1.0	1.2	1.3

(a) The number of samples taken for each parameter were as follows:

LC12 and LC11: 12 to 20 samples

LC6: 3 or 4 samples

LC10: 5 to 14 samples

(b) All concentrations are mg/l, except pH and specific conductance, which is in micro-siemens per centimetre (us/cm)

TABLE 4-5

CHANGES IN AVERAGE CONCENTRATION OF PARAMETERS IN EAST CHANNEL, MACKENZIE RIVER AFTER PASSING INUVIK

Parameter	Percent Change[a] LC11	LC10
1. pH	+ 1.3	+ 2.6
2. Specific Conductance	+ 11.5	- 4.0
3. Total Hardness	+ 6.6	+ 6.6
4. Suspended Solids	+ 36.0	+15.1
5. Dissolved Oxygen	+ 7.1	+ 1.8
6. Dissolved Nitrogen	- 3.4	0.0
7. Dissolved Phosphorous	0.0	+11.8
8. Dissolved Sodium	+ 32.5	+10.4
9. Dissolved Chloride	+ 10.6	+11.5
10. Dissolved Sulphate	+ 15.8	+10.9
11. Dissolved Iron	+500	-12.5
12. Dissolved Potassium	0.0	+ 8.3

(a) Percent changes are relative to values measured at station LC1.2

4.5 River Mixing

Theoretical considerations supported by field studies have shown that wastes discharged into a receiving stream may travel a considerable distance before the waste becomes uniformly mixed across the stream. Research has indicated that mixing (dispersion) within the stream is an important factor when considering waste discharges, since it is the basic mechanism whereby the concentration of contaminants is reduced to levels at which the receiving water can assimilate them (32), 33, 34, 35).

The rate of dispersion depends upon current velocity, turbulence, relative densities and viscosities, and a number of other geometric and dynamic characteristics of both the receiving water and the contaminant stream. The mechanics of dispersion and the relationships between these factors are extremely complex, so discrepancies usually exist between predicted dispersion rates and actual ones. The reliability of forecasts can be improved by making extensive current velocity surveys or by doing direct tracer studies. However, reasonable approximations, sufficient for the present study, can be made by formulating a simplified mathematical model of the receiving stream, and solving the equation of transport of the contaminant plume obtained (36). Reports of research into mixing in rivers having characteristics similar to the Mackenzie (34, 35, 38, 39, 40) provide sufficient information for the construction of a simplified model.

4.5.2 Mackenzie River Model

The Mackenzie River is a relatively straight, uniform river that has few channel configurations that would accelerate or facilitate the lateral dispersion of a waste stream. A waste stream discharged into the Mackenzie at the shore, would tend to follow near the shore, and to spread laterally across the river fairly slowly as it proceeded downstream (36). This mixing phenomena is illustrated schematically in Figure 4-1.

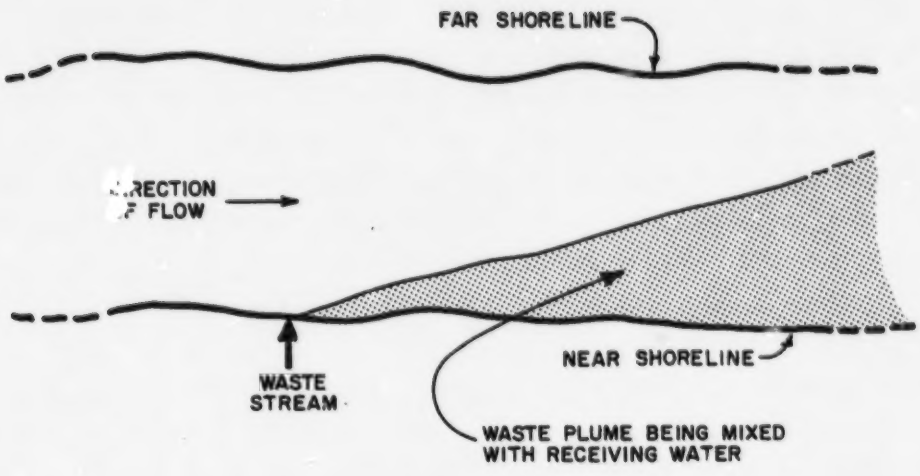

FIGURE 4-1: LONGITUDINAL MIXING

With direction and assistance from Dr. Hugo B. Fischer* a simplified mathematical model of the longitudinal mixing of waste streams entering the Mackenzie River was developed. River geometry was derived from airphotos, and the complete set of navigational charts for the river published by the Canadian Hydrographic Service. Flow characteristics were taken from available stream flow data (22, 23, 24, 25, 26, 27) and representative stage-discharge relationships from river gauging stations (28, 29).

Transport equations were developed for minimum flows under ice cover. The equations indicate that, due to the Mackenzie's wide, relatively shallow channel section, and the relative scarcity of channel features that would accelerate mixing, a waste stream would travel a long distance downstream from its source before it became more or less uniformly dispersed across the river (36, 41). The only reach where this appears not to be the case is the Ramparts (between Norman Wells and Fort Good Hope), where channel constriction and channel depth would accelerate mixing. The mathematical model indicates that a partially mixed plume entering the upstream end of the Ramparts would be well mixed before leaving the downstream end.

* Dr. Fischer, Professor of Civil Engineering, University of California, Berkley, is a recognized authority on mixing and dispersion characteristics of rivers.

Therefore, except for the modification which occurs at the Ramparts, it appears that the distribution of effluent across the channel would not be uniform, for a long distance below the point of discharge. Therefore, the amount of contaminant that may be found at a particular location along the river, would depend upon where the sample was taken across the width of the channel. For example, it appears that effluent discharged at river side from Fort Providence, on the east bank of the river, would not affect water quality at the shoreline at Jean Marie River, on the west bank. On the other hand, effluent from Fort Providence would be less dilute near the shore at Wrigley, also on the east bank, because of incomplete mixing.

The results of the mixing analysis have been used in the prediction of coliform concentrations at community locations, due to discharge from communities further upstream. It is stressed, however, that actual monitoring by taking and testing water samples, is the only way to confirm the suitability of any water body at any location for use as a potable water source.

Sample calculations of mixing are included in Appendix B.

5. WATER POLLUTION CONTROL

5.1 General

The preservation of our natural water resources is of vital importance. The principal considerations in the disposal of wastewater are public health, aesthetics, economics, and the preservation of environmental quality. The maintenance of a satisfactory receiving water quality depends upon achieving a proper balance between the volume and character of the receiving water and the volume and quality of the wastewater discharged into it. Pollution of receiving waters by waste discharges is the degrading of these waters to the detriment of existing or potential uses.

The purpose of conditioning or treating sewage is to prepare it for ultimate disposal into a receiving water. The sewage will then undergo further purification by natural processes. It must be borne in mind that even after a wastewater is processed in a normal municipal treatment system, the final product is not potable water and adequate disposal of the treated effluent still must be acheived.

The ultimate disposal of a community's sewage is, in almost every case, by means of dilution. The degree of treatment required before discharge may vary from none whatever to a very high degree, depending on the size, condition, and subsequent uses of the receiving body of water. The disposal of sewage is rendered practicable not merely by the dispersion of waste matter in large volumes of water but by the purification processes inherent in natural bodies of water.

A cautious approach must be taken relative to sewage disposal in arctic and subarctic rivers, since these river ecosystems are considerably more fragile than those in more temperate climates (19).

In our analyses of potential pollutional parameters, we have based dilution ratios on the lowest daily flow rates recorded for the rivers at the various communities (or our estimates of this flow rate), coupled with the daily quantities of potential raw pollutants produced by each community, estimated for the year 2000. This approach is quite conservative, and ensures that the minimum pollutant dilution ratio is considered in each case. This approach may be considered more severe than necessary, but it is obvious that if concentrations of potential pollutants are below pollution causing levels under the most critical conditions of ice cover and minimum flow, conditions which prevail for only a few days of occasional years, then they will be well below pollution causing levels on a seasonal or annual basis.

5.2 Regulations and Guidelines

There are two Federal Acts, namely the Northern Inland Waters Act of 1970 and the Fisheries Act of 1952, that could apply to pollution control in the Northwest Territories. These Acts are somewhat general in wording and intent. The Northern Inland Waters Act provides for the licensing of waste discharges, where "waste" is defined as any substance that would degrade or alter water quality.

The Fisheries Act prohibits the deposition of any deleterious substance in water frequented by fish, where deleterious substance is defined as any substance that would degrade or alter the quality of the water so as to harm fish or fish habitat, or to impair the use by man of fish that frequent the water. The Fisheries Act has recently been strengthened by the addition of Chapter 14 (formerly Bill C-38) which contains the following points:

(a) The maximum penalty is increased from $5,000 to $50,000 for a first offence and $100,000 for subsequent offences.

(b) Courts have been empowered to order positive corrective action and to issue orders to refrain from committing further offences.

(c) Those responsible for pollution are liable for the costs of cleanup.

The Environmental Protection Service has published, as a discussion paper, proposed interim treatment requirements for communities in the Northwest Territories (42), including the thirteen communities under consideration here. These proposed treatment requirements are shown below in Table 5-1. It is to be noted that EPS did not recommend effluent disinfection for any community.

TABLE 5-1
ENVIRONMENTAL PROTECTION SERVICE'S PROPOSED
INTERIM TREATMENT GUIDELINES

	Community	Treatment Level*
1.	Fort Providence	E (no discharge)
2.	Jean Marie River	E
3.	Fort Simpson	B (secondary)
4.	Wrigley	A (primarily)
5.	Fort Norman	A
6.	Norman Wells	B
7.	Fort Good Hope	A or E
8.	Arctic Red River	A or E
9.	Aklavik	A
10.	Inuvik	B
11.	Fort Liard	B
12.	Nahanni Butte	A or E
13.	Fort McPherson	B

* The full definitions of the treatment levels indicated are:

A: Removal of settleable, suspended, and floatable matter and location of outfall to minimize health hazards.

B: Requirements of A plus removal of dissolved organic and colloidal matter.

E: Storage of waste whereby no liquid effluent can discharge to surface or ground waters.

5.3 Potential Pollution Concerns

5.3.1 Public Health

Coliform bacteria are present in high concentration in sewage. They are relatively easy to detect and measure, and have long been used as a standard indicator for detecting the presence of sewage. Although members of the coliform group are rarely harmful to health themselves, their presence in high concentrations, particularly fecal coliforms, indicates probable sewage pollution and the potential existence of pathogenic organisms.

Specified disease-causing or pathogenic organisms, including viruses, are not normally measured because there are many different kinds and they are usually present in very low concentrations or not at all, depending on whether members of the contributing population are suffering from the respective enteric diseases. Therefore, to attempt to detect pathogens in sewage or a receiving water would require taking very large samples, concentrating them by precipitation, filtration, or centrifugation, and performing many kinds of microbiological tests. Such a procedure would be prohibitively expensive.

Therefore, microbiological drinking water standards relate to total and fecal coliform concentrations. These standards have developed over the years on an empirical basis so that if the coliform standards are met, it is reasonably certain that pathogens, whether bacteria or viruses, will not be present in concentrations that could result in illness.

The Department of National Health and Welfare (Canada) has set standards for allowable total and fecal coliform concentrations in drinking water and in raw water before treatment (20). Table 5-2 below shows the standards that would have to be met by a river supply, depending on the degree of treatment given to the water before use as drinking water.

There is some evidence that pathogenic bacteria may survive in proportionately higher numbers than coliforms at 0°C. Fecal streptococci were found to survive approximately 4 times as well in an ice-covered river in one study (43), and viruses are known to survive better than coliforms at lower temperatures in freshwater, based on work by Gilcreas and Kelly as referred to in (37). Salmonella were studied in a stream at 0°C, but data were inadequate to define a relationship between salmonella types and coliforms (45).

The above evidence indicates that the risk to public health in applying national standards to northern waters is probably somewhat higher than applying them in southern waters. However, the Federal standards given in Table 5-2 are in our opinion reasonable for application in the North. They are consistent with U.S. Public Health Service standards (44) and World Health Organization standards (46). It must be borne in mind that microbiological standards are set in order to reduce health risks to very low or negligible levels. <u>However, the risk can never be completely eliminated</u>.

It must be emphasized that the minimum degree of treatment that should be applied to any surface water before domestic use is disinfection. Disinfection should be carried out even for rivers or streams that receive no domestic sewage discharges, since the potential exists for disease transmission from animals in an upstream watershed. In communities of the size range under consideration, the normal method of disinfection is by addition of chlorine. However, several of the communities reportedly either do not chlorinate their water supply at all or do not chlorinate it effectively.

TABLE 5-2

RAW WATER TOTAL AND FECAL COLIFORM STANDARDS (20)

Standard	Total Coliforms per 100 ml	Fecal Coliforms per 100 ml
Objective[a]: At least 95% of the samples in any consecutive 30-day period should have a coliform density of less than.....	100	10
Acceptable Limit[b]: At least 90% of the samples in any consecutive 30-day period should have a coliform density of less than.....	1000	100
Maximum Permissible Limit[c]: At least 90% of the samples in any consecutive 30-day period should have a coliform density of less than.....	5000	1000

a To meet the objective, treatment by chlorination alone is sufficient.

b Complete or partial treatment including chlorination is required. Complete treatment consists of coagulation, sedimentation, filtration, and disinfection. Partial treatment consists of filtration and disinfection.

c Complete water treatment is required.

Coliforms, as well as other enteric micro-organisms, tend to be preserved and remain viable longer at lower temperatures. A number of studies have been carried out on coliform survival in an ice-covered river in Alaska (43, 45, 47). These studies were carried out on a 210-mile reach of the Tanana River, which receives domestic sewage effluent from Fairbanks via the Chena River. For several reasons, the results of these studies may be of limited usefulness with respect to sewage discharges in the Mackenzie Basin. First, flow regimes in the rivers are probably different. The Tanana River exhibited discharge anomalies in which the flow rose and dropped between sampling stations. The cause of the drops in flow was not known, but was thought to be due to loss of water from the river channel to adjacent groundwater reservoirs. Second, the percent survivals found in the studies were based on the assumption that the first sampling station represented 100 percent survival, although this station was some distance downstream from the discharge point, and considerable settling of organisms, die-away, and predation must already have occured. Third, the survival of organisms in a treated effluent, as from Fairbanks which has primary treatment at the time of the studies, would be higher than organism survival for a raw sewage discharge, since considerable die-away and settling out of organisms occurs in the treatment plant. Finally, it was apparently assumed that coliforms were completely mixed in the Tanana River. This assumption may not be valid, although the smoothness of the die-away curves suggests that samples were taken within the plume.

Despite the above noted shortcomings, the lack of research in this area has necessitated the use of these studies as the best available information for predicting coliform survival in an ice-covered river. The estimated percent survival curve for total and fecal coliforms shown in Figure 5-1 is based on an average of the results given in two of the studies (43, 47), adjusted to account for the estimated flow time between Fairbanks and the first sampling station on the Tanana River.

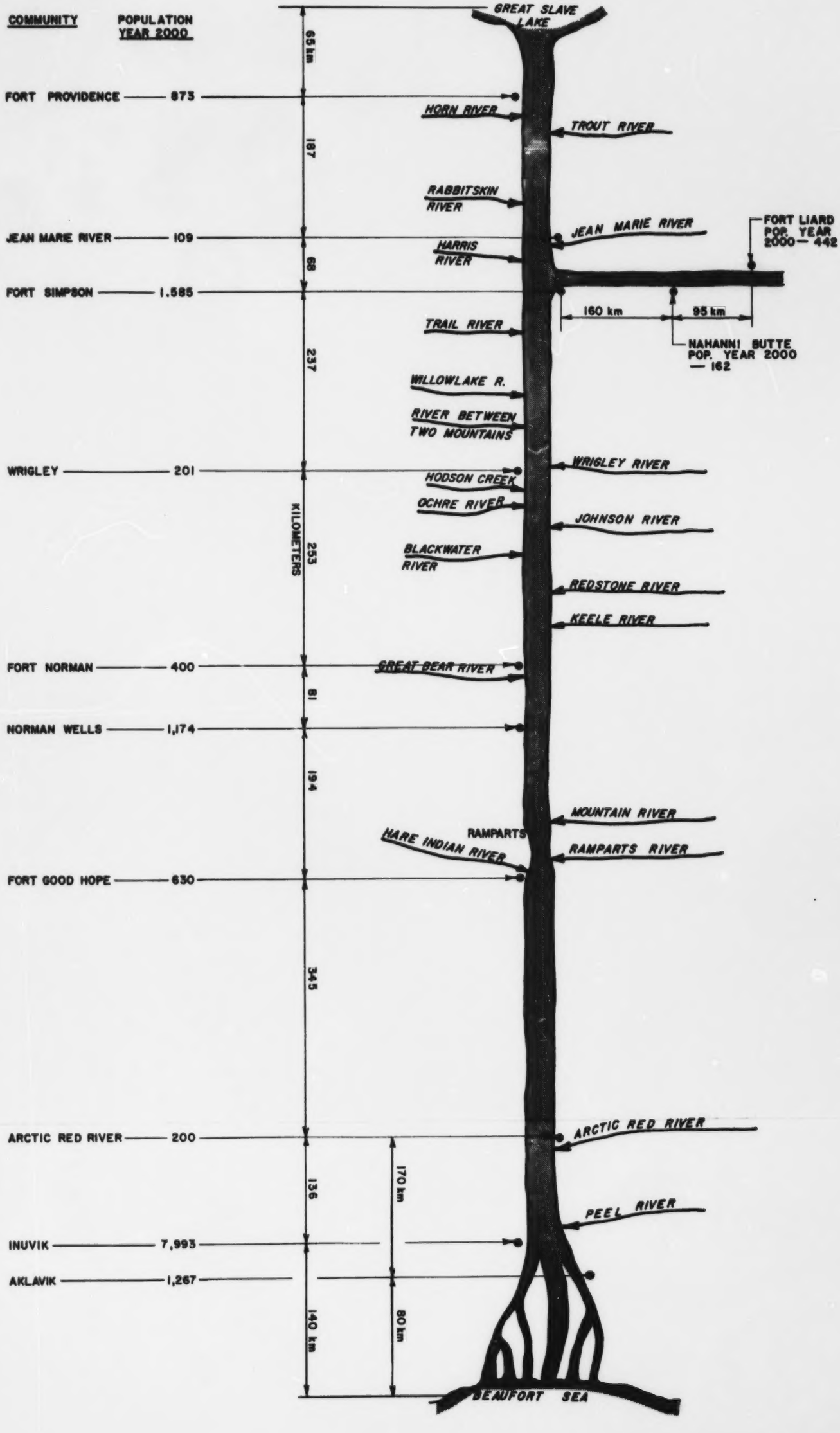

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FIGURE 3-1

Two sets of estimates have been made of fecal coliform concentrations at the shoreline of each of the thirteen study communities, based on the year 2000 potential coliform contributions of all upstream communities. The first set of estimates, presented in Table 5-3, neglects die-away in the stream, and considers only mixing, as shown by the example in Appendix B. It is presented to demonstrate the enormous effect of dilution. The second set of estimates, presented in Table 5-4, is an amalgamation of the best available information, and includes a consideration of mixing and expected coliform survival as shown in Figure 5-1.

The values in Table 5-3 are essentially the intermediate numbers used in calculating the values in Table 5-4. They are presented to give an indication of the massive dilution available, even with incomplete mixing in the river.

The estimates given in Table 5-4 are the fecal coliform concentrations expected in the year 2000 <u>if all communities have raw outfall discharges to the rivers</u>. It can be seen be seen from these estamates that raw sewage discharge from existing communities would not render the bacteriological quality of river water unacceptable for public water supply, as defined in Table 5-2, at any community. It is possible that Aklavik, Fort Good Hope, and Norman Wells might have to treat a river water supply beyond simple chlorination, if a sampling program showed that 5 percent of the samples taking in any 30-day period had 10 or more fecal coliforms per 100 ml. River water supplies for all the other communities should also be sampled, but the estimates given in Table 5-4 suggests that these supplies would not require treatment beyond chlorination for bacteriological characteristics, the minimum treatment required for any surface water supply.

It must be emphasized that the coliform concentration estimates are very crude, and are intended to give only a general idea of possible future microbiological water quality. In order to assess the potability of a water supply source, the source must be sampled as described in the Canadian Drinking Water Standards and Objectives (20), in order to determine actual coliform concentrations. If it is found that the standards are being exceeded, there are four corrective options to consider;

1. find an alternative source of water supply;
2. upgrade the treatment applied to the raw water, beyond chlorination;
3. provide effective disinfection of upstream sewage discharges;
4. cease direct sewage discharges to the river upstream, during critical seasons or throughout the year.

TABLE 5-3

ESTIMATED YEAR - 2000 FECAL COLIFORM CONCENTRATIONS AT SHORELINE OF EACH COMMUNITY, NEGLECTING DIE-AWAY

(Number per 100 ml)

	SOURCE OF FECAL COLIFORMS													
Community	Inuvik	Aklavik	Ft. McPherson	Arctic Red R	Ft. Good Hope	Norman Wells	Ft. Norman	Wrigley	Ft. Simpson	Jean Marie R	Ft. Providence	Nahanni Butte	Ft. Liard	Total Fecal Coliforms[c]
Inuvik	-	-	-	13	40	37	25	13	100	7	55	10	28	328
Aklavik	-	-	1,285	-	-	-	-	-	-	-	-	-	-	1,285
Ft. McPherson[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctic Red R	-	-	-	-	8	37	25	13	100	7	55	10	28	283
Ft. Good Hope	-	-	-	-	-	37	25	13	100	7	55	10	28	275
Norman Wells	-	-	-	-	-	-	100	14	55	4	69	6	16	264
Ft. Norman	-	-	-	-	-	-	-	27	48	4	72	5	14	170
Wrigley	-	-	-	-	-	-	-	-	0	1	86	0	0	87
Ft. Simpson[b]	-	-	-	-	-	-	-	-	-	0	106	0	0	106
Jean Marie R	-	-	-	-	-	-	-	-	-	-	0	-	-	0
Ft. Providence[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nahanni Butte	-	-	-	-	-	-	-	-	-	-	-	-	0	0
Ft. Liard	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a It is assumed that there is no significant upstream fecal coliform contributions above these communities.

b The Concentration given for Ft. Simpson is given for the shoreline opposite the community since Ft. Simpson's water intake is located across the river.

c Total coliform concentration just upstream of the community, as a result of all upstream discharge, considering dilution but neglecting die-away.

TABLE 5-4

ESTIMATED YEAR - 2000 FECAL COLIFORM CONCENTRATIONS AT SHORELINE OF EACH COMMUNITY

(Number per 100 ml)

	SOURCE OF FECAL COLIFORMS													
Community	Inuvik	Aklavik	Ft. McPherson	Arctic Red R	Ft. Good Hope	Norman Wells	Ft. Norman	Wrigley	Ft. Simpson	Jean Marie R	Ft. Providence	Nahanni Butte	Ft. Liard	Total Fecal Coliforms[d]
Inuvik	-	-	-	0	0	0	0	0	1	0	0	0	0	1
Aklavik	-	-	13	-	-	-	-	-	-	-	-	-	-	13
Ft. McPherson[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Arctic Red R	-	-	-	-	0	1	1	0	1	0	1	0	0	4
Ft. Good Hope	-	-	-	-	-	7	1	0	1	0	1	0	0	10
Norman Wells	-	-	-	-	-	-	30	0	1	0	1	0	0	32
Ft. Norman	-	-	-	-	-	-	-	2	1	0	1	0	0	4
Wrigley	-	-	-	-	-	-	-	0	0	0	2	0	0	2
Ft. Simpson[c]	-	-	-	-	-	-	-	-	-	0	5	0	0	5
Jean Marie R	-	-	-	-	-	-	-	-	-	-	0	-	-	0
Ft. Providence[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Nahanni Butte	-	-	-	-	-	-	-	-	-	-	-	-	0	0
Ft. Liard[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0

a Fractions of coliform organisms are taken to the nearest whole number. In may cases, this number is zero.

b It is assumed that there is no significant upstream fecal coliform contributions above these communities.

c The coliform concentration for Ft. Simpson is given for the shoreline opposite the community, since Ft. Simpson's water intake is located across the river from the community.

d Total coliform concentration just upstream of the community, as a result of all upstream discharges.

The existing situation relative to contamination of community water supply is better than indicated above, since many of the communities do not withdraw water from the Mackenzie River and most communities do not have raw sewage outfall discharges.

The important question of casual use by trappers and hunters, canoeists and campers is more difficult to resolve. Water should not be casually ingested from any point on any river, but obviously the health risk becomes very high when water is taken immediately downstream from a sewage outfall. However, this type of casual water use is apparently traditional in the Mackenzie Basin, and often is expected in wilderness areas. In order to completely eliminate health risks associated with sewage discharges it would be necessary to sterilize the sewage, since even chlorinated sewage that has received secondary treatment can still have fecal coliform concentrations of up to 50,000 per 100 ml, and could still present some risk immediately downstream of an outfall. It should be noted that chlorinated sewage is more toxic to fish than raw sewage (56, 57).

Even if sewage discharges to the river were not allowed, there would still be a health risk associated with drinking river water downstream from populated areas, since urban runoff can contain high coliform concentrations, and pathogens. As intimated previously, even taking water from a stream located in an isolated wilderness area still constitutes a health hazard, due to the presence of wild animals which may carry diseases harmful to man. For the camper, boiling water taken from any stream has been the traditional way of reducing this health hazard. We believe that posting of warnings (in appropriate languages) at outfall locations would be prudent, as would public education to discourage the drinking of raw river water from any natural source.

Another potential problem relates to fish. Fish many be contamined by sewage discharges, and can be killed by high concentrations of sewage. At study community locations, the small inputs of sewage would not reduce dissolved oxygen by dangerous amounts, nor would they cause other toxic or harmful effects. In one sense, small sewage inputs can be considered beneficial since they can enhance general habitat productivity and increase fish populations. Fish may tend to frequent waters near outfalls because food is more abundant there, due to nutrient input.

However, there is some risk that pathogens in the water could contaminate fish and be passed on to people that eat the fish. Federal Fisheries researchers have indicated that they do not think this would be a significant problem (48, 49). The hazard could be eliminated by cooking the fish. Apart from the potential risks from sewage, fresh-water fish can contain tapeworms and liver flukes that are dangerous to man. Fish tapeworms can cause anemia, which, if undetected and untreated, can lead to death. Infection from all biological sources can be completely prevented if fresh fish is cooked (48, 50), therefore, cooking should be encouraged in any case.

An additional point relative to fish contamination is that, while there is some doubt as to the importance of contamination by enteric bacteria of freshly caught fish, there is little doubt that it is much less important that the subsequent contamination during handling and processing (49, 50). This subsequent contamination can arise from the introduction of microorganisms by fishermen and handlers.

5.3.2 Dissolved Oxygen

Domestic sewage contains biodegradeable organic materials, the decomposition of which exerts a demand for the oxygen dissolved in the receiving water. This demand is generally measured in sewage under laboratory conditions at 20°C, over a 5 day period, and is termed the five day biochemical oxygen demand (BOD_5).* Exertion of the BOD results in the reduction of the dissolved oxygen (DO) concentration in the receiving water.

* The five day 20°C test was developed in England, where few rivers had a flow time to the sea of more than five days, and summertime water temperatures were in the range of 20°C. At low temperatures, the rate of decomposition, and therefore the rate at which BOD is exerted is much lower, although the ultimate total oxygen demand is of course the same. The effect of low temperature, therefore, is to spread out the oxygen demand (depletion) and to reduce the oxygen sag effect. This generally reduces the environmental import of sewage, but also spreads the influence at a reduced rate farther downstream then in warm waters.

Dissolved oxygen concentrations in ice-covered rivers are naturally low because the ice prevents absorption of oxygen from the atmosphere as well as the generation of oxygen through photosynthesis by algae and green plants in the river. Thus late winter, towards the end of the ice-covered period, is the most critical time of year relative to the effects of BOD on the rivers. Extensive sampling of a large number of Alaskan rivers has indicated that the dissolved oxygen concentration in some rivers falls below 1.0 mg/l during winter (16, 17). However, the Mackenzie Basin rivers under consideration apparently do not experience such low concentrations.

The lowest values measured in the Mackenzie, Liard, or Peel River, according to published Water Survey of Canada data (31), are approximately 5 mg/l. We have confirmed that these low values have been measured in March, although in some years the dissolved oxygen concentrations are high, and in other years they are low at the same location. The minimum measured dissolved oxygen concentration near the communities are shown in Table 5-5, together with our estimates of the maximum potential DO deficits associated with sewage discharges.

In estimating maximum deficits, two assumptions have been made for the sake of simplicity. The first is that of complete mixing. Poor mixing would result in isolated pockets or streams of water with lower DO, but the aquatic life in the river would on the whole not be significantly affected. The second assumption is that all of the ultimate BOD is exerted in producing the deficit. In actual fact, the maximum deficits would be some fraction of the ultimate BOD. However, in this case, where potential deficits are so small, the difference is negligible.

All of the potential DO deficits are negligible, with the exception of that associated with Inuvik. Even if all the potential DO deficits associated with communities between Great Slave Lake and the main channel of the Mackenzie River in the Delta area, including communities on the Liard and Peel Rivers, were added together, the resulting deficit in the main channel would still be negligibly small.

TABLE 5-5

DISSOLVED OXYGEN

Community	Minimum Measured Values, mg/l (31)	Maximum Potential Downstream Deficit mg/l[a], Complete Mixing[a] mg/l	1% Mixing[b] mg/l
Ft. Providence	6.9 (March 28, 1972)	0.0007	0.07
Jean Marie River	-	0.0001	0.01
Ft. Simpson	7.6 (March 25, 1972)	0.0008	0.08
Wrigley	-	0.0001	0.01
Ft. Norman	-	0.0002	0.02
Norman Wells	7.4 (March 21, 1972)	0.0004	0.04
Ft. Good Hope		0.0002	0.02
Arctic Red River	-	0.0001	0.01
Inuvik	5.2 (March 14, 1972)	1.8050[d]	total[d]
Aklavik	-	0.0143	1.43[c]
Ft. Liard	6.0 (March 27, 1972)	0.0020	0.20
Nahanni Butte	-	0.0006	0.06
Ft. McPherson	5.0 (March 22, 1972)	0.0195	1.95[c]

(a) Based on complete mixing and minimum river flow, and on the assumption that all of the ultimate BOD is exerted in producing a DO deficit.

(b) Based on assumptions as above, but with mixing of sewage with only one percent of the minimum recorded flow.

(c) Potentially a remotely significant effect over a limited area.

(d) Potentially a significant effect.

The question arises as to what minimum DO concentration is acceptable for maintaining fish and other aquatic life. A value of 5.0 mg/l with occasional fluctuations to as low as 3.0 mg/l, has been recommended for warm water fish habitats (51). Mr. Justice Thomas Berger has recommended the maintenance of 6.0 mg/l in receiving waters, relative to pipeline construction camps (19). This value is supported by the U.S. Department of the Interior publication, Water Quality Criteria, which states that, for the cold water biota..."For good growth and the general well being of trout, salmon, and their associated biota, DO conditions should not be below 6.0 mg/l" (53). It should be noted, however, that natural DO levels in Mackenzie basin rivers do normally fall to about 5.0 mg/l in the winter.

The natural fluctuations in dissolved oxygen in the Mackenzie basin rivers occur over a wide range, compared to which the tiny DO deficits that could potentially occur due to community sewage inputs are negligibly small. The exception is Inuvik, whose BOD input in the year 2000 could cause a DO deficit of about 1.8 mg/l, which is quite significant compared to a natural river DO level of about 5.0 mg/l. It is very likely that the potential maximum deficit would not occur until after the East Channel waters mixed with the ocean water of the Beaufort Sea. Based on the minimum flow volicty in the east arm of 0.06 m/sec, and a distance of approximately 150 km from Inuvik to the ocean, it would take a waste discharge about 29 days to reach the sea. Data on BOD exertion rates at near 0°C is limited and gives widely varying values (13, 15). It is known that in rivers at 20°C practically all of the carbonaceous BOD is exerted in 20 days. However, one study measured reaction rates at near 0°C that were 3 to 7 times slower than at 20°C (13). Based on this study, one would expect the maximum deficit in an ice covered river near 0°C to occur only after 60 to 140 days. The beaufort Sea is a very large reservoir of dissolved oxygen, so oxygen demand exerted after discharge into the ocean would be assimilated easily.

Based on the above evidence, it is our opinion that the maximum potential DO deficit of 1.8 mg/l would not occur in the east arm of the Mackenzie River. However, winter discharge of raw sewage from Inuvik could still cause a measurable drop in DO concentration in that reach under winter conditions. Incomplete mixing would further accentuate a potential problem.

5.3.3 Suspended Solids

Suspended solids can be of concern if they are present in concentrations that impair any use of the water, including preventing or inhibiting fish spawning. The rivers under consideration have very high natural sediment loads in the spring. Even under winter regime, the dilution of sewage from any of the communities would be so great that the clarity of the water would not be affected. Measured minimum (winter) suspended solids concentrations are given in Table 5-6, together with estimates of maximum potential contributions that sewage from each community could add.

TABLE 5-6
SUSPENDED SOLIDS

Community	Minimum Measured Values, mg/l (31)[a]	Maximum Potential Sewage Contribution, mg/l	
		Complete mixing[b] mg/l	1% Mixing[c] mg/l
Ft. Providence	< 1	0.0005	0.05
Jean Marie River	-	0.0001	0.01
Ft. Simpson	2	0.0006	0.06
Wrigley	3	0.0001	0.01
Ft. Norman	3	0.0001	0.01
Norman Wells	2	0.0003	0.03
Ft. Good Hope	2	0.0002	0.02
Arctic Red River	< 1	0.0001	0.01
Inuvik	< 1	1.2835	128.35[e]
Aklavik	-	0.0102	1.02
Ft. Liard	1	0.0014	0.14
Nahanni Butte	-	0.0004	0.04
Ft. McPherson	3	0.0139	1.39

(a) The minimum values for suspended solids concentration correspond to the minimum river flows during winter.

(b) Average river concentrations are given, based on the assumption of complete mixing.

(c) Concentrations are given assuming that the effluent stream is mixed with only one percent of the minimum recorded river flow.

(d) Potentially a remotely significant effect, over a limited area.

(e) Potentially a significant effect, at certain times.

5.3.4 Nutrients

Phosphorus and nitrogen inputs from the communities could have no significant effect on river biotas. Eutrophication has not occured in the north in large rivers because of small nutrient inputs and low temperatures. Most northern rivers are low in nutrients. A value not exceeding 0.1 mg/l phosphorus has been recommended by the US Department of the Interior, with the nitrogen not to exceed the phosphorous concentration by more than a factor of about 10 for flowing streams in temperate climates (53). Justice Berger has suggested concentrations of 0.15 and 1.0 mg/l for phosphorous and nitrogen (19). Measured values of phosphorous and nitrogen, and estimated sewage contributions of nutrients are given in Table 5-7.

TABLE 5-7
NUTRIENTS

Community	Average Measured Values, mg/l (32)[a]		Maximum Potential Sewage Contribution, mg/l[b]	
	Phosphate[c]	Nitrogen[d]	Phosphate[c]	Nitrogen[d]
Ft. Providence	0.016	0.5	0.000020	0.00012
Jean Marie River	-	-	0.000003	0.00001
Ft. Simpson	0.028	0.6	0.000030	0.00014
Wrigley	0.070	0.7	0.000004	0.00002
Ft. Norman	-	-	0.000006	0.00003
Norman Wells	0.029	0.6	0.000010	0.00008
Ft. Good Hope	0.029	0.5	0.000007	0.00004
Arctic Red River	0.064	0.6	0.000003	0.00001
Inuvik	-	-	0.061462	0.32088
Aklavik	-	-	0.000486	0.00255
Ft. Liard	0.007	-	0.000067	0.00036
Nahanni Butte	-	-	0.000022	0.00010
Ft. McPherson	0.21	0.7	0.000669	0.00347

(a) Average measured values of total phosphate and total Kjeldahl nigrogen are given.
(b) For simplicty, average river concentrations are given, assuming complete mixing.

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5.3.5 Dissolved Materials

Domestic sewage normally contains a large variety of dissolved ions, including cations such as sodium, magnesium, calcium, and potassium, and anions such as carbonate, chloride, sulphate, nitrate and phosphate. A maximum concentration of 2000 mg/l total dissolved solids has been recommended for fish habitats (52). The concentration of total dissolved solids (TDS) in the river will not be measurably affected by sewage inputs of dissolved material, as indicated by the data presented in Table 5-8.

TABLE 5-8
DISSOLVED MATERIAL

Recommended Maximum Level for Fish Habitat
of Total Dissolved Solids (TDS)
is 2000 mg/l (52)

Community	Average Measured Values, mg/l (32)	Maximum Potential Sewage Contribution, mg/l	
		Complete Mixing[a]	1% Mixing[b]
Ft. Providence	131	0.00127	0.127
Jean Marie River	-	0.00015	0.015
Ft. Simpson	127	0.00157	0.157
Wrigley	163	0.00019	0.019
Ft. Norman	-	0.00036	0.036
Norman Wells	124	0.00084	0.084
Ft. Good Hope	136	0.00044	0.044
Arctic Red River	157	0.00013	0.013[d]
Inuvik	-	3.48000[c]	348.
Aklavik	-	0.02760	2.760
Ft. Liard	76	0.00387	0.387
Nahanni Butte	-	0.00115	0.115
Ft. McPherson	161	0.03750	3.750

(a) Average river concentrations are given, based on the assumption of complete mixing.

(b) Concentrations are given assuming that the effluent stream is mixed with only one percent of the minimum recorded river flow.

(c) Potentially a remotely significant effect, over a limited area.

(d) Potentially a significant effect.

5.4 Effluent Quality Requirements

With the exception of potential disease transmission as indicated by coliform concentrations, none of the parameters associated with sewage discharges (including parameters not specifically discussed above) would have a significant effect on the receiving water at or downstream from any of the locations considered, except for potential DO deficit downstream from Inuvik. Even under conditions of poor mixing, with the waste discharges mixed with a small proportion of the river flow, effects would be insignificant. For example, if the waste discharges mixed with only one percent of the river water, and the pollutant concentrations were thus one hundred times higher than shown in the preceding Tables, the potential effects on that one percent of the river would still be negligible, except for Inuvik, and perhaps Aklavik and Fort McPherson. It is expected that any temporary effects of pollutants left in isolated river pockets or streams would be removed each year at breakup. Any sludge deposits, even immediately below an outfall, would also be significantly disturbed and mixed.

In summary, it is our opinion that Inuvik is the only community at which there may be reason to provide treatment facility for the removal of pollutants other than microorganisms. For all other communities, there is no environmental justification for treatment, except perhaps as a means of increasing the effectiveness of effluent disinfection.

For Inuvik, treatment would not be required if effluent could be stored through the winter and discharged only during the ice-free season, since the larger volume of effluent to be assimilated would be more than offset by East Channel's much larger assimilative capacity during that period. In fact, the storage pond would perform some degree of treatment itself, rendering the effect of the discharge of even smaller significance. We understand that a lagoon large enough to store sewage throughout the winter could be constructed at Inuvik.

6. CONCLUSIONS AND RECOMMENDATIONS

A summary of the principal conclusions and recommendations resulting from the study are as follows.

1. Based on our evaluation, the treatment levels recommended by EPS appear to be somewhat arbitrary and overly defensive. Except in the case of Inuvik, little justification has been found for treating sewage that could be discharged from existing communities into the Liard, Peel and Mackenzie Rivers, up to year - 2000 population (assuming that wastewater characteristics are not changed by industrial development). Discharge of raw sewage would, however, increase slightly the potential for transmission of certain diseases.

   For any community where wastewater management were judged necessary, managing wastewater flows so that they are reduced to acceptable levels during critical seasons might be the most economical means of meeting environmental and public health objectives. Sufficient storage for the retention of excess amounts of wastewater through critical seasons would be necessary. Retention would of course provide a degree of treatment, which would further reduce impacts.

2. It probably would not be necessary to reduce coliform levels in sewage from existing communities prior to discharge, up to expected year - 2000, populations, in order to protect community water supplies taken from the rivers. This conclusion must be checked for any community drawing river water, by a sampling program. Any surface water supply should receive a minimum treatment of disinfection. It is possible that by the year 2000, river water supplies at Norman Wells, Fort Good Hope, and Aklavik could require treatment beyond disinfection.

3. The protection of casual users of raw river water cannot be ensured, neither by treatment and disinfection of discharges nor by disallowing discharges. Of course, the hazard to such users would be high immediately downstream of an outfall. It is recommended that outfall locations be posted, and that drinking of raw river water from any location be discouraged.

4. There is some public health risk associated with eating raw fish that have recently been swimming in water around an outfall. However, there is also a risk of contracting tapeworms or liver flukes by eating raw fish taken from any location. Cooking fish eliminates both hazards. It is recommended that eating raw fish be discouraged.

5. For best aesthestics and good mixing, it is recommended that raw sewage outfalls be installed so as to discharge below the lowest water level. There should never be an open discharge near the shoreline or on top of the ice. A properly installed outfall will be safer for public health and for the environment than a storage pit with an uncontrolled overflow.

6. It is recommended that the coliform concentration estimates contained in this report be checked through a coliform sampling program. We suggest that sets of samples be taken in the Mackenzie River downstream of Fort Simpson. Samples should be taken during every season, and should be taken at a suitable number of transverse points across the river in order to define the effluent plume. Several sampling locations should be defined downstream from Fort Simpson and the same locations should be used each time. Fecal coliform concentrations should be measured and correlated with location, date of sampling, river velocity, and the characteristics of Fort Simpson's wastewater discharge.

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APPENDIX A

APPENDIX A

ABBREVIATIONS AND CONVERSION TABLE

Distance

cm	=	centimetre	ft	=	foot
in	=	inch	km	=	kilometre
m	=	metre	mi	=	mile

Area

m^2	=	square metre	km^2	=	square kilometre
ft^2	=	square foot	mi^2	=	square mile
ha	=	hectare			

Volume

l	=	litre	m^3	=	cubic metre
ft^3	=	square foot	gal	=	gallon (1)

Miscellaneous

ig	=	imperial gallon	TDH	=	total dynamic head
igm	=	imperial gallons per minute	mg/l	=	milligrams per litre
igd	=	imperial gallons per day	hp	=	horsepower
igcd	=	imperial gallons per capita day	mig	=	million imperial gallons
			migd	=	million imperial gallons per day
psi	=	pounds per square inch			
cfs	=	cubic feet per second			

(1) Gallons are British Imperial throughout the report.

ENGINEERING UNITS CONVERSION TABLE

Metric To British

1 cm	= 0.394 in
1 m	= 3.281 ft
1 m	= 1.094 yd
1 km	= 0.621 mile
1 ha	= 2.471 acre
1 ha	= 3.861×10^{-3} mile^2
1 km^2	= 2.471 acre
1 m^3	= 35.31 ft^3
1 m^3	= 1.308 yd^3
1 L	= 3.531×10^{-2} ft^3
1 L	= 0.220 gallon (Imp)
1 m^3	= 220 gallon

British to Metric

1 inch	= 2.540 cm
1 foot	= 0.305 m
1 yard	= 0.914 m
1 mile	= 1.609 km
1 acre	= 0.405 ha
1 acre	= 4.05×10^{-3} km^2
1 mile^2	= 259.0 ha
1 foot^3	= 2.832 x 10-2 m^3
1 foot^3	= 28.32 L
1 yard^3	= 0.765 m^3
1 gallon	= 4.546 L
1 gallon	= 4.546×10^{-3} m^3

Metric to Metric

1,000 m = 1 km
100 ha = 1 km^2
1,000 litre = 1 m^3

British to British

1 gallon = 0.161 ft^3
1 foot^3 = 6.23 gallons

Abbreviations

m = metre
km = kilometre
L = litre
ft = foot
yd = yard
unit^2 = square units
unit^3 = cubic units
Gallons are British Imperial

APPENDIX B

APPENDIX B

EXAMPLE CALCULATION OF COLIFORM CONCENTRATIONS IN THE MACKENZIE RIVER, DUE TO SEWAGE DISCHARGE.

The purpose of Appendix B is to illustrate the methods used to calculate the potential coliform concentrations reported in Tables 5-3 and 5-4.

Table 5-3 reports the concentration of coliforms at settlement locations that would result from upstream sewage discharges, at year 2000 populations, considering mixing the effluent with river water (dilution), but neglecting die-off of organisms. Table 5-4, reports the concentrations that would be expected to occur considering both mixing and die-off.

Flow mixing is a complex phenomenon, and is the subject of continuing study. Relationships which appear to describe mixing fairly precisely exist for some specific cases which have been investigated directly by experiment. However, laboratory results generally relate to uniform flow in straight channels of uniform cross section, whereas geometry and flow in natural river channels commonly exhibit wide variations.

In spite of these limitations, judicious use of available information (30, 32, 34, 35, 38, 39, 40) will yield reasonable predictions of flow mixing rates in some natural streams. Dr. Hugo B. Fischer (see p. 4-13) assisted with the development of simplified relationships describing the mixing of a waste stream into the Mackenzie River, at minimum flows, under ice cover. Canadian Hydrographic Service Charts were used to assess river channel characteristics affecting mixing and in the selection of representative values for channel widths and depths. Stream flow data (22, 23, 24, 25, 26) and representative stage - discharge relationships were used to assess flow rates, and in the selection of representative values for average flow velocities. While the relationship derived and the predictions made must be recognized as approximations only, they are believed to be sufficiently correct for the purposes of the order-of-magnitude assessment presented in this report.

The diagram below illustrates the notation used.

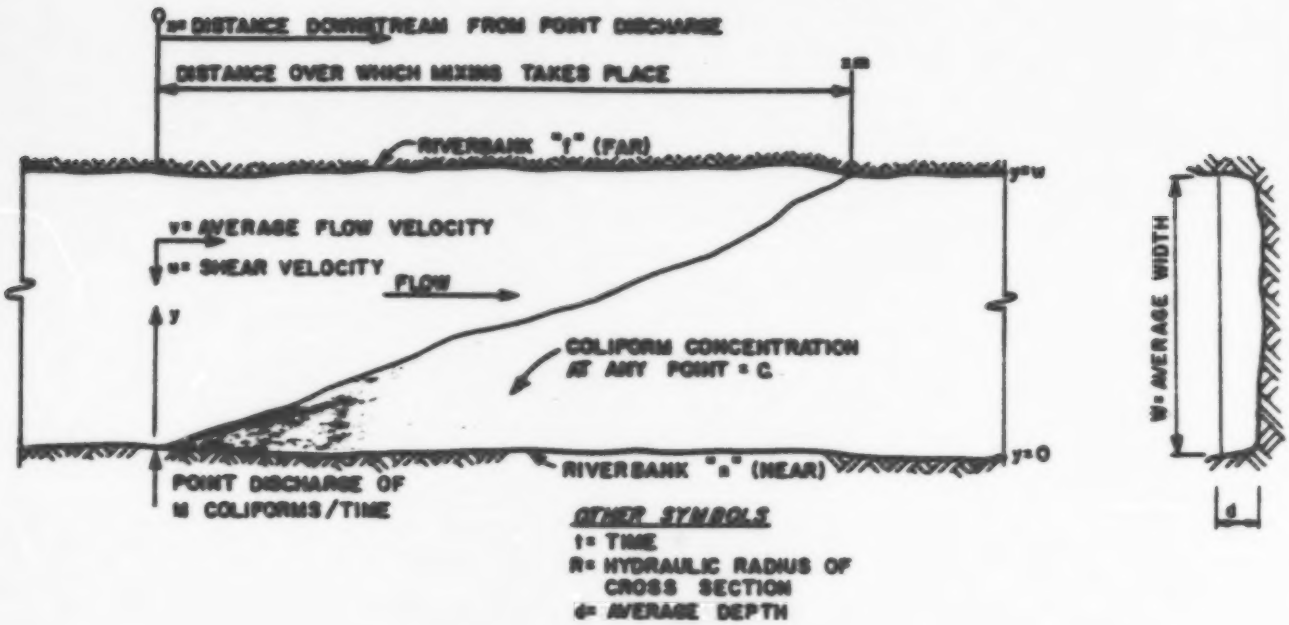

FIGURE B-1 LONGITUDINAL MIXING

NOTES:

1. X_m is defined as the river cross section at which the coliform concentration C_f at the far bank, due to the discharge at X_o first reaches a level equal to 90% of the concentration C_n, at the near bank due to the same discharge.

   ie. At X_m, $C_f = 0.9\ C_n$

2. The river channel is idealizes as a rectangular section of width W and depth d.

3. Flow down the river channel is characterized by an average velocity v, equal to $q/A = q/Wd$, where q is the flow discharge per unit time.

4. Flow across the river channel ("shear flow") u can be taken to be 0.1 v (41).

5. A typical rate of fecal coliform production is 95×10^9 organisms per capita-day (see p. 3-16).

DEFINITIONS AND RELATIONSHIPS

A = Flow Area (m^2)

$A = Wd$

P = Wetted Perimeter (m)

Without ice cover, $P = 2d + W$

With ice cover, $P = 2d + 2W$

R = Hydraulic Radius (m)

$R = \frac{A}{P}$ (definition)

Without ice cover, $R = \frac{Wd}{2d + W}$, and, since $d \ll W$, $R \approx d$

With ice cover, $Ri = \frac{Wd}{2d + 2W}$, and, since $d \ll W$, $R \approx \frac{d}{2}$

E = Transverse Mixing Coeficient (m^2/sec)

$E = kRu \approx kdu$ (without ice) and $\approx$ 0.5 kdu (with ice)

k = dimensionless mixing coefficient

The usual range of k for natural, slowly meandering rivers is 0.4 to 0.8 (41). A reasonable value for a relatively regular river such as the Mackenzie is 0.5 (36).

$C_{(x,y)}$ = Concentration Downstream Due To a Point Discharge at $x=0, y=0$ (mass/unit volume)

If x=0, y=0 is located on the stream centerline,

$$\frac{C(x,y)}{Co} = \frac{1}{\sqrt{4\pi x'}} \sum_{n=0}^{\infty} e^{-\frac{(y' + n)^2}{4x'}}$$ (dimensionless) (6.10 ref 41)

WHERE $Co = \frac{M}{d W}$ (mass/unit volume)

$y' = \frac{y}{W}$ (dimensionless)

$x' = \frac{xE}{v W^2}$ (dimensionless)

Solution of Equation 6.10 indicates that for $x' \geq 0.1$, the concentration is within 5% of its mean value everywhere on the cross section (41).

Xm = Distance Required for Complete Mixing (m)

"Complete" mixing is defined as C far bank $\geq$ 90% C near bank.

For mid-channel discharge,

$$Xm = \frac{0.1 \ v \ W^2}{E} \qquad (6.11, \text{ ref } 41).$$

For side discharge, the transverse travel distance W is doubled,

$$Xm = \frac{0.1 \ v \ (2W)^2}{E} = \frac{0.4 \ v \ W^2}{E} \qquad (\text{ref } 41) \quad (6.11a)$$

EXAMPLE

As an illustration, the relationships reported above will be used to evaluate the effects of a waste stream discharged at the riverbank at Wrigley, on water near the shoreline at Fort Norman, in winter.

The following values are believed to characterize the reach of the Mackenzie River between Wrigley and Fort Norman, at minimum flow, under ice cover:

width W = 700 m
depth d = 5 m
velocity v = 0.5 m/sec

(a) Evaluate the travel distance required for complete mixing of the waste stream from Wrigley:

from 6.11a, $Xm = \frac{0.4 \ v \ W^2}{E}$, where $E = \frac{ku \ d}{2}$ (6), = 0.5 kdu,

and k = 0.5 (36),
d = 5 m
u = 0.1V = 0.1 (0.5 m/sec) = 0.05 m/sec

$\therefore$ E = 0.5 (0.5) (5 m) (0.05 m/sec) = 0.05 m/sec

Since W = 700 m,

$$X_m = \frac{0.4(0.5\ m/sec)\ (700\ m)^2}{0.0625\ m^2/sec} = 1.5 \times 10^6 m = 1560\ km$$

Therefore, if it were not for the influence of the Ramparts, mixing would not be complete by the time that the Delta was reached.

(b) Evaluate the concentration of fecal coliforms expected to be found under ice near the shoreline at Fort Norman due to the discharge at Wrigley, neglecting die away:

Wrigley's forecast year 2000 population is 201. Therefore, the predicted rate of fecal coliform production and discharge is:

$$\frac{(201\ persons)\ (95 \times 10^9\ fecal\ coliforms/person\text{-}day)}{86{,}400\ seconds\ per\ day} = 221 \times 10^6\ fc/sec$$

From 6.10,

$$\frac{C(x,y)}{Co} = \frac{1}{\sqrt{4\pi x'}} \sum_{n=o}^{n=\infty} e^{-\frac{(y \pm n)^2}{4x'}}$$

The travel distance downstream from Wrigley to Fort Norman is 253 km, therefore

$$x' = \frac{xE}{v(2W)^2} \quad (6.10c;\ 2W \text{ because of side discharge})$$

$$= \frac{(253 \times 10^3 m)\ (0.0625\ m^2/sec)}{(0.5\ m/sec)\ (2 \times 700\ m)^2} = 0.0161$$

Wrigley and Fort Norman are both on the east bank of the river. Therefore,

$$y = 0 \quad \text{and} \quad y' = \frac{y}{W}\ (6.10b) = 0$$

The concentration at completely homogeneous mixing

$$Co = \frac{M}{vdW}\ (6.10a) = \frac{221 \times 10^6\ fc/sec}{(0.5\ m/sec)(5m)(700m)} =$$

$$126{,}285\ fc/m^3 = 12.6\ fc/100\ ml$$

From 6.10,

$$C(253,0) = \frac{12.6/100\ ml}{4 \times 3.14 \times 0.016} \sum_{n=0}^{\infty} \frac{1}{\ln^{-1} \frac{(0 \pm n)^2}{4 \times .016}}$$

$$= \frac{12.6/100\ ml}{.450} \sum_{\cdot}^{\cdot} \ldots, 5.8 \times 10^{-8}, 1, 5.8 \times 10^{-8} \ldots$$

$$= 12.6/100\ ml \quad \left(\frac{1}{0.450}\right) = 28.0 \text{ fecal coli/100 ml}$$

Note: The value given in the text (table 5-3) is 27. The difference results from the use of a graphical solution for the large number of computations needed to proceduce tables 5-3 and 5-4.

(c) Evaluate the concentration of fecal coliforms expected to be found under ice near the shoreline at Fort Norman due to the discharge at Wrigley, considering both mixing and die-off:

The travel time from Wrigley to Fort Norman is:

$$\frac{253\ km}{0.5\ m/sec} = \frac{253{,}000\ m}{0.5\ m/sec} = 506{,}000\ sec = 5.86\ days$$

Figure 5-1 (following page 5-7) indicates that only 6% of fecal coliforms would survive as long as 5.8 days in an ice covered river.

∴ Concentration of surviving fecal coliforms =

$$(0.06)(28.0/100\ ml) = 1.68 \approx 2\ fc/100\ ml$$

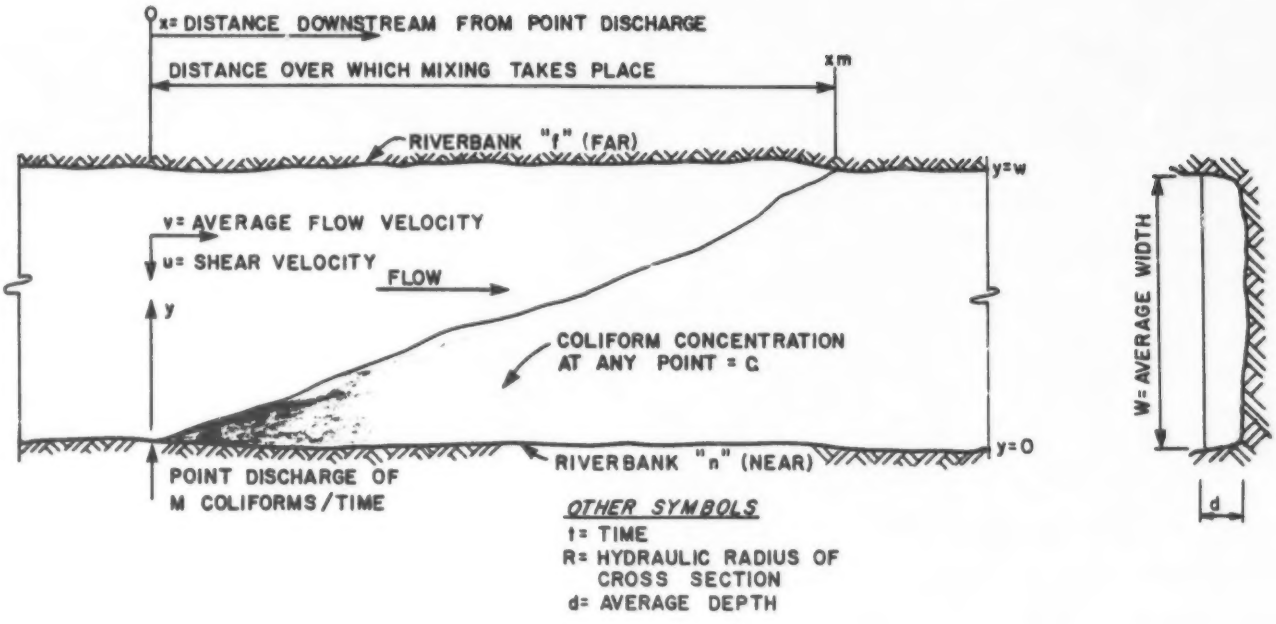

FIGURE B-1 LONGITUDINAL MIXING

TABLE 5-4

ESTIMATED YEAR - 2000 FECAL COLIFORM CONCENTRATIONS AT SHORELINE OF EACH COMMUNITY

(Number per 100 ml)

	SOURCE OF FECAL COLIFORMS													
Community	Inuvik	Aklavik	Ft. McPherson	Arctic Red R	Ft. Good Hope	Norman Wells	Ft. Norman	Wrigley	Ft. Simpson	Jean Marie R	Ft. Providence	Nahanni Butte	Ft. Liard	Total Fecal Coliforms[d]
Inuvik	-	-	-	0	0	0	0	0	1	0	0	0	0	1
Aklavik	-	-	13	-	-	-	-	-	-	-	-	-	-	13
Ft. McPherson[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Arctic Red R	-	-	-	-	0	1	1	0	1	0	1	0	0	4
Ft. Good Hope	-	-	-	-	-	7	1	0	1	0	1	0	0	10
Norman Wells	-	-	-	-	-	-	30	0	1	0	1	0	0	32
Ft. Norman	-	-	-	-	-	-	-	2	1	0	1	0	0	4
Wrigley	-	-	-	-	-	-	-	0	0	0	2	0	0	2
Ft. Simpson[c]	-	-	-	-	-	-	-	-	-	0	5	0	0	5
Jean Marie R	-	-	-	-	-	-	-	-	-	-	0	-	-	0
Ft. Providence[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Nahanni Butte	-	-	-	-	-	-	-	-	-	-	-	-	0	0
Ft. Liard[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	0

a Fractions of coliform organisms are taken to the nearest whole number. In may cases, this number is zero.

b It is assumed that there is no significant upstream fecal coliform contributions above these communities.

c The coliform concentration for Ft. Simpson is given for the shoreline opposite the community, since Ft. Simpson's water intake is located across the river from the community.

d Total coliform concentration just upstream of the community, as a result of all upstream discharges.

TABLE 5-3

ESTIMATED YEAR - 2000 FECAL COLIFORM CONCENTRATIONS AT SHORELINE OF EACH COMMUNITY, NEGLECTING DIE-AWAY

(Number per 100 ml)

	SOURCE OF FECAL COLIFORMS													
Community	Inuvik	Aklavik	Ft. McPherson	Arctic Red R	Ft. Good Hope	Norman Wells	Ft. Norman	Wrigley	Ft. Simpson	Jean Marie R	Ft. Providence	Nahanni Butte	Ft. Liard	Total Fecal Coliforms[c]
Inuvik	-	-	-	13	40	37	25	13	100	7	55	10	28	328
Aklavik	-	-	1,285	-	-	-	-	-	-	-	-	-	-	1,285
Ft. McPherson[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctic Red R	-	-	-	-	8	37	25	13	100	7	55	10	28	283
Ft. Good Hope	-	-	-	-	-	37	25	13	100	7	55	10	28	275
Norman Wells	-	-	-	-	-	-	100	14	55	4	69	6	16	264
Ft. Norman	-	-	-	-	-	-	-	27	48	4	72	5	14	170
Wrigley	-	-	-	-	-	-	-	-	0	1	86	0	0	87
Ft. Simpson[b]	-	-	-	-	-	-	-	-	-	0	106	0	0	106
Jean Marie R	-	-	-	-	-	-	-	-	-	-	0	-	-	0
Ft. Providence[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nahanni Butte	-	-	-	-	-	-	-	-	-	-	-	-	0	0
Ft. Liard	-	-	-	-	-	-	-	-	-	-	-	-	-	-

a It is assumed that there is no significant upstream fecal coliform contributions above these communities.

b The Concentration given for Ft. Simpson is given for the shoreline opposite the community since Ft. Simpson's water intake is located across the river.

c Total coliform concentration just upstream of the community, as a result of all upstream discharge, considering dilution but neglecting die-away.

POOR

QUALITY

ORIGINAL